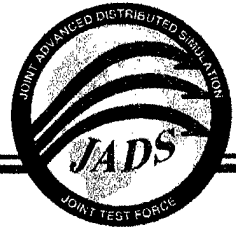


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JADS JT&E



JADS Final Report

December 1999

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**Joint Advanced Distributed Simulation
Joint Test Force
2050A 2nd St. SE
Kirtland Air Force Base, New Mexico 87117-5522**

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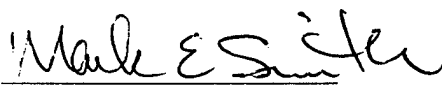
JADS Final Report

24 December 1999

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Executive Summary

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E) was chartered by the Deputy Director, Test, Systems Engineering and Evaluation (Test and Evaluation)¹, Office of the Secretary of Defense (OSD) (Acquisition and Technology) in October 1994 to investigate the utility of advanced distributed simulation (ADS) technologies for support of test and evaluation (T&E). The JADS program was Air Force led with Navy and Army participation. This report addresses the overall findings, conclusions and recommendations of JADS.

JADS directly investigated ADS applications in three slices of the T&E spectrum: the System Integration Test (SIT) explored ADS support of precision guided munitions (PGM) testing; the End-To-End (ETE) Test investigated ADS support for command, control, communications, computers, and intelligence (C4I) testing; and the Electronic Warfare (EW) Test evaluated ADS support for EW testing. The JADS Joint Test Force also observed, or participated at a modest level in, ADS activities sponsored and conducted by other agencies. The purpose of this effort was twofold. First JADS could leverage select agencies to narrow our focus. Second, involvement with other agencies using this technology would help broaden the conclusions developed in our three dedicated test areas.

Based on its charter, JADS developed questions in the form of issues. These issues were used to

Table ES1. JADS Issues and Objectives Summary

Issues	Objectives
Issue 1: What is the present utility of ADS, including distributed interactive simulation (DIS), for T&E?	Objective 1-1: Assess the validity of data from tests using ADS, including DIS, during test execution. Objective 1-2: Assess the benefits of using ADS, including DIS, in T&E.
Issue 2: What are the critical constraints, concerns, and methodologies when using ADS for T&E?	Objective 2-1: Assess the critical constraints and concerns in ADS performance for T&E. Objective 2-2: Assess the critical constraints and concerns in ADS support systems for T&E. Objective 2-3: Develop and assess methodologies associated with ADS for T&E.
Issue 3: What are the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future?	Objective 3-1: Identify requirements for ADS systems that would provide a more complete T&E capability in the future.

¹ This office is now the Deputy Director, Developmental Test and Evaluation.

structure the JADS test and evaluation approach. JADS then developed objectives and measures from these issues to guide the analysis. The first issue focused on assessing the utility of ADS for T&E. The second issue focused on constraints, concerns, and methodologies when using ADS for T&E. And, the third issue focused on requirements for future ADS development to improve its T&E utility. The questions raised by the T&E community concerning the use of ADS technology to support T&E included: "Will it work with the rigor necessary to support testing?" "Are the data gathered using ADS valid and/or credible?" "Is the technology mature enough for a T&E tool?" and "How affordable is using this technology for testing?" JADS was structured to answer these questions. Table ES1 summarizes the program-level issues and objectives that are addressed in detail in Section 2 of the body of the report.

The following summarizes the answers the final report provides to the three issues.

The three JADS tests each demonstrated the utility of ADS for specific classes of systems. ADS architectures can provide valid, credible data and can therefore be used in support of rigorous T&E. While the benefits and costs of ADS are very program specific, JADS data strongly suggest that ADS can be a cost effective test tool. In many instances the technology provides for enhanced testing capability at reduced costs.

JADS used both quantitative and qualitative techniques to address critical concerns, constraints and methodologies. JADS experience was that concerns and constraints are more programmatic than technical. JADS assessed network and communications performance in three key areas: bandwidth, latency and data quality. A key finding of JADS was that in most cases these were indeed only concerns. Network and communications were never insurmountable constraints for the JADS tests and shouldn't be for future tests if JADS developed test-planning methodologies are followed. Programmatic challenges on the other hand are many and diverse. A strong systems engineering approach to test planning and design is critical to success.

JADS gathered valuable information on the maturity of ADS to support T&E in general. Based on JADS experience this capability is mature enough to support most applications to T&E. In terms of the requirements to provide a more complete T&E capability in the future, ADS is still evolving and issues remain in areas such as fidelity, data structures, security, scalability, emission representations and reactive terrain.

Lessons Learned

Near the end of the JADS program, we came to the realization that the term "Advanced Distributed Simulation (ADS)" was potentially misleading when used in the context of T&E. The word "simulation" is something of a turn off for testers, because they are sharply focused on collecting real data whenever they can. In fact, distributed architectures can be used effectively to support actual testing. A system under test (SUT) can be incorporated into a distributed architecture and subjected to valid stimuli that can originate at a number of remote sites. The collection of stimuli may indeed create an "artificial environment" which is perceived by the SUT, but if the stimuli are valid, real performance data can be collected on the performance of the SUT. That is testing. (As an aside, even in traditional testing, the test environment is, more

often than not, artificial.) The fact that a stimulus originates at some distance from the SUT location is immaterial so long as it is a valid stimulus. Distributed architectures can provide robust test environments and offer opportunities to conduct concurrent, rather than sequential test events, that generate actual SUT performance data. Distributed testing, as we see it, is a subset of ADS. There will almost certainly be opportunities to use ADS as a simulation tool in support of acquisition programs, but there will also be potential benefits to using distributed architectures as genuine test tools. This report further characterizes lessons learned as either technical or programmatic. In some cases the lessons learned applied to more than one category and thus appear multiple times. For each category an attempt was made to distill the lessons learned in that category into some key findings.

Technical Lessons Learned

- Careful design and thorough integration testing are required regardless of whether you're developing and linking a new simulation or linking an existing stand-alone simulation.
- For the foreseeable future, distributed testing must rely on the use of simulations that were not designed to necessarily work together. In most cases it is more cost effective to develop interface units than it is to modify existing simulations. Careful design and testing of these interfaces are required to ensure they perform desired functions without adding large processing delays.
- Distributed testing applications have unique and sometimes stringent network performance requirements for latency and latency variation. There are many design decisions that impact network performance. Special instrumentation and thorough testing are required to ensure the network is meeting performance requirements.
- Special network instrumentation is required to monitor network performance during both development and test execution. Time stamping and synchronization are unique aspects of distributed testing that require special attention. Live players also have unique instrumentation requirements for distributed test applications.
- There are many unique aspects to distributed test control that require a carefully selected mix of centralized and local control. The central control facility must have the display and communications capabilities to know total system health in real time. Total system health includes not only the status of the real, virtual, and constructive players, but also the data processing and collection systems and the system synchronization mechanism. Real-time processing of system data is essential to efficient test conduct.
- Testing in software quality is not generally possible. Poorly designed software rarely emerges from testing in any better condition. Conversely one should not take the position that well planned and developed software does not require testing. The development and coordination of complex models to support distributed testing requires extraordinary attention to configuration management issues. The added complexity of distributed testing over stand-alone applications makes following proven software engineering standards and

procedures critical. Configuration control is particularly problematic and requires extraordinary attention.

- Distributed testing requires strong systems integration and systems engineering skills. There are important considerations in the planning process that are not well understood and therefore may lead to unanticipated costs. This report sheds light on many of these considerations. There are two unique aspects of distributed testing that affect data analysis and must be planned for early. The first is the requirement to do real-time data analysis to support test control and test execution. The second is that distributed testing generates large amounts of data in a short time. Without careful planning and testing of the entire data collection, processing, and analysis process, test analysts will be either hopelessly lost or hopelessly buried in data.
- JADS techniques require a SUT simulation with realistic input-output capabilities.
- Distributed-testing architecture can provide a tool for operational interoperability assessments if proper fidelity exists for each simulation. The Navy's Distributed Engineering Plant (DEP) concept is very similar to JADS in placing emphasis on interoperability and realistic stimuli. DEP appears to be a legacy for JADS.
- High level architecture (HLA) was adequate to support the JADS EW Test, but it required a lot of tuning and trial and error testing on the part of JADS and Defense Modeling and Simulation Organization (DMSO). Better documentation that provides insight into the inner-workings of the runtime infrastructure (RTI) would help. Thorough instrumentation is required to track and isolate problems between the network and the RTI. The T&E community needs to actively participate in the Architecture Management Group to promote the development of HLA standards and products that meet the needs of the T&E community.

Programmatic Lessons Learned

- The number and types of procedural lessons learned JADS identified clearly substantiate the need to develop standards for the use of ADS.
- The increased complexity of a distributed test can result in a small to medium increase in cost. Actual costs, however, are application specific. Cost drivers include synthetic environment (SE) complexity, fidelity requirements, experienced personnel requirements, configuration management, and network interfaces. If a new or modified simulation must be developed to support the conduct of the distributed test, costs can be medium to high.
- Many diverse skills are required to support distributed testing. A system integrator with strong systems engineering experience and adequate empowerment is required to pull everything together.

Recommendations

JADS has identified requirements that must be introduced into distributed testing systems if they are to support a more complete T&E capability. The following recommendations include requirements for distributed testing of systems that would help improve T&E capability in the future.

- Address distributed testing approaches in the test and evaluation master plan (TEMP).
- Focus on the ability of distributed testing to overcome any identified test limitations.
- Program managers and operational test agencies (OTAs) should embrace and implement Simulation, Test and Evaluation Process (STEP) and Simulation Based Acquisition (SBA). Distributed testing is an enabling technology for STEP and SBA.
- Use the integrated product team (IPT)/integrated product and process development (IPPD) process to facilitate utilization of assets across phases of development including requirements definition, engineering, manufacture and development, test and evaluation, operations and training.
- Mid- and upper-management should encourage/require T&E vision beyond the scope of individual test events and specific systems.
- When making a distributed testing go/no go decision, compare distributed testing costs to the costs of the alternative method(s).
- Use JADS-developed distributed testing cost guidance to help identify the optimal mix of distributed testing and traditional means of testing.
- Department of Defense (DoD) should develop infrastructure to reduce the costs of linking.
- Use a distributed test environment over the life of a program.
- Incorporate distributed testing into the curricula for formal T&E and acquisition schools.
- DoD should nurture groundbreaking programs such as Foundation Initiative 2010 and Joint Strike Fighter.
- Use JADS-developed distributed testing methodologies such as test planning, verification and validation.
- Each organization using distributed testing should plan for a centralized test control and analysis capability. Such a facility can be low cost and located anywhere. In addition to test control, it can be used to enhance real-time data analysis and test efficiency.

- Require the PMs provide a realistic HWIL simulation of the SUT with realistic representation of voice, data, and data-links.

1.0 JADS Overview

1.1 Background

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E) was chartered by the Deputy Director, Test, Systems Engineering and Evaluation (Test and Evaluation)², Office of the Secretary of Defense (OSD) (Acquisition and Technology) in October 1994 to investigate the utility of ADS technologies for support of developmental test and evaluation (DT&E) and operational test and evaluation (OT&E). The program was Air Force led with Army and Navy participation. Science Applications International Corporation (SAIC) and the Georgia Tech Research Institute provided contracted technical support.

1.2 Purpose

The JADS JT&E charter focused on three issues: What is the present utility of ADS, including distributed interactive simulation (DIS), for test and evaluation (T&E); What are the critical constraints, concerns, and methodologies when using ADS for T&E; and what are the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future. The JADS Joint Test Force (JTF) directly investigated ADS applications in three slices of the T&E spectrum: the System Integration Test (SIT) explored ADS support of air-to-air missile testing; the End-to-End (ETE) Test investigated ADS support for command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) testing; and the Electronic Warfare (EW) Test evaluated ADS support for EW testing. Each test applied the JADS objectives and measures as appropriate to conduct its evaluation. The JTF was also chartered to observe or participate at a modest level in ADS activities sponsored and conducted by other agencies in an effort to help narrow the focus and broaden conclusions developed in our three direct test areas.

The following is a synopsis of each of the JADS distributed tests.

The SIT explored the utility of using ADS to support cost-effective testing of an integrated missile weapon/launch aircraft system in an operationally realistic scenario. The SIT was a Distributed Interactive Simulation (DIS) -based test and consisted of two phases, each of which culminated in three flight missions. The missions simulated a single shooter aircraft launching an air-to-air missile against a single target aircraft. In the Linked Simulators Phase (LSP), the shooter, target, and missile were all represented by simulators. In the Live Fly Phase (LFP), the shooter and target were represented by live aircraft and the missile by a simulator.

The EW Test evaluated the utility of ADS in an EW environment. The first distributed test phase employed a linked architecture using Department of Defense's (DoD) high level architecture (HLA) which included a digital simulation model of the ALQ-131 self-protection jammer, threat simulation facilities, and constructive models that supported replication of the open air environment. In the second phase, an installed systems test facility (ISTF) was

² This office is now the Deputy Director, Developmental Test and Evaluation.

substituted for the digital model. In both distributed test architectures, system performance data were compared with live fly data for verification and validation (V&V).

The ETE Test investigated the utility of ADS to support testing of C4ISR systems. It conducted its T&E utility evaluation in a DIS-based, ADS-enhanced environment using the Joint Surveillance Target Attack Radar System (Joint STARS) as one component of a representative C4ISR environment.

The ETE Test used ADS to assemble an enhanced environment for testing C4ISR systems. The intent was to provide a complete, robust set of interfaces from sensor to weapon system, including the additional intermediate nodes that would be found in a tactical engagement. The test traced a thread of the complete battlefield process from target detection to target assignment and engagement at corps level using distributed testing. It also allowed the tester to evaluate the thread as a whole or the contribution of any of the parts individually and to evaluate what effects an operationally realistic environment had on the system under test.

The ETE Test was designed to add additional entities in a seamless manner to the battlefield seen by Joint STARS. In addition, adding some of the complementary suite of other command, control, communications, computers and intelligence (C4I) and weapon systems with which Joint STARS would interact enabled the test team to evaluate the utility of a ADS-enhanced environment.

All three tests evaluated the capability of the JADS Test Control and Analysis Center (TCAC) to control a distributed test of this type and to remotely monitor and analyze test results.

1.3 Test and Evaluation Approach

1.3.1 Test Issues and Objectives

Based on its charter, JADS developed questions in the form of issues. These issues were then used to structure the JADS test and evaluation approach. JADS then developed objectives and measures from these issues to guide the analysis. The first issue focused on assessing the utility of ADS for T&E. The second issue focused on constraints, concerns, and methodologies when using ADS for T&E. And, the third issue focused on requirements for future ADS development to improve its T&E utility. The questions raised by the T&E community concerning the use of ADS technology to support T&E included: "Will it work with the rigor necessary to support testing?" "Are the data gathered using ADS valid and/or credible?" "Is the technology mature enough for a T&E tool?" and "How affordable is using this technology for testing?" JADS was structured to answer these questions. Table 1 summarizes the program-level issues and objectives described in detail below. The subobjectives and measures used to evaluate these issues and objectives are addressed in Section 2.

Table 1. JADS Issues and Objectives Summary

Issues	Objectives
Issue 1: What is the present utility of ADS, including DIS, for T&E?	<p>Objective 1-1: Assess the validity of data from tests using ADS, including DIS, during test execution.</p> <p>Objective 1-2: Assess the benefits of using ADS, including DIS, in T&E.</p>
Issue 2: What are the critical constraints, concerns, and methodologies when using ADS for T&E?	<p>Objective 2-1: Assess the critical constraints and concerns in ADS performance for T&E.</p> <p>Objective 2-2: Assess the critical constraints and concerns in ADS support systems for T&E.</p> <p>Objective 2-3: Develop and assess methodologies associated with ADS for T&E.</p>
Issue 3: What are the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future?	Objective 3-1: Identify requirements for ADS systems that would provide a more complete T&E capability in the future.

ISSUE 1: What is the present utility of ADS, including DIS, for T&E?

Some questions from the testing community concerning the use of ADS to support T&E were: "What does it cost?" "Does it work?" "Will it support T&E earlier in the acquisition process?" To be useful for T&E, ADS must either provide operational realism equivalent to live testing at reduced cost, or it must provide increased operational realism at an affordable cost. Both the costs and benefits of using ADS are important measures to determine the utility of distributed testing to support T&E. Two objectives were used to address this issue.

Objective 1-1: Assess the validity of data from tests using ADS, including DIS, during test execution.

The key to the utility of distributed testing for T&E lies in its ability to provide valid data when used during test execution. If ADS does not provide valid data during test execution, then it has no utility. If it does provide valid data, then it may have a great deal of utility.

Objective 1-2: Assess the benefits of using ADS, including DIS, in T&E.

Once the validity of ADS data in test execution was established, the benefits of using ADS in T&E were addressed. The benefits of ADS for all phases of T&E as well as for the early phases of the acquisition process were addressed in the subobjectives and measures for this objective.

ISSUE 2: What are the critical constraints, concerns, and methodologies when using ADS for T&E?

This issue looked at characteristics such as fidelity and maturity of the technology required for T&E. The execution of a test will determine if the necessary maturity does exist as well as identify the strengths and weaknesses in the maturity of the technologies for other T&E use. JADS used three objectives to address this issue.

Objective 2-1: Assess the critical constraints and concerns in ADS performance for T&E.

In the design of a specific ADS T&E methodology to support a test, assembling a network of constructive, virtual, and live simulations presents a host of new technical and management issues for testers. These issues may include such problems as simulation identification and capability evaluation, integration of models, interface development and testing, network development, network operations and scheduling management, and verification and validation of entire networks. In addition, factors such as seamlessness, fidelity, and latency need to be considered based on the desired output or function of the ADS T&E methodology. These design issues as well as the performance shortfalls of the resulting implementation were addressed in this objective. This objective also looked at the reliability of the ADS network assembled for each test program. While each individual component in a ADS network has its own reliability, the linked distributed testing network of simulations and live systems used in a test may have a totally different reliability. This was an important maturity issue JADS addressed during the JT&E. Can the ADS network infrastructure be reliably scheduled? Will the network run when initiated? Will it operate continuously for an adequate amount of time to complete the test event? The ADS T&E methodology infrastructure must possess some adequate level of operational reliability to be useful to support the T&E.

Objective 2-2: Assess the critical constraints and concerns in ADS support systems for T&E.

This objective addresses the maturity of the overall ADS support infrastructure. The impact, as well as the increased use of simulation, that the distributed nature of ADS testing has upon existing configuration management systems and data management and analysis support systems was addressed.

Objective 2-3: Develop and assess methodologies associated with ADS for T&E.

The JTF modified existing procedures as necessary or developed additional procedures for planning, designing, testing, and operating ADS methodologies used in the JT&E. JADS also identified the strengths and weaknesses of the various management, network, and simulation issues related to assembling an ADS infrastructure. To help determine the feasibility and utility of ADS test methods, JADS published *A Test Planning Methodology – From Concept Development Through Test Execution* which can be found at www.jads.abq.com.³

ISSUE 3: What are the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future?

The test community has not yet developed its requirements for specialized support in the form of network and simulation standards to support T&E. ADS is still evolving and issues remain in areas such as fidelity, data structures, security, scalability, emission representations, and reactive terrain. Objective 3-1 was used to address this issue.

Objective 3-1: Identify requirements for ADS systems that would provide a more complete T&E capability in the future.

For any given application of ADS in a specific test program, there are technological alternatives for implementation. For example, only one of several networks (e.g., Defense Simulation Internet [DSI] or leased commercial) may be employed during a given test, but networks may not be equally capable of supporting that test. In the development of the test concepts for this JT&E, alternatives were considered and some were rejected as not appearing mature enough to support the test during its life span. Also, to scope this JT&E at a reasonable level of cost, choices were made concerning which systems and which test issues would be selected for evaluation. For these reasons, a complete assessment of the maturity of this technology as a whole cannot be made based solely on JADS results. However, JADS gathered valuable information on the maturity of ADS to support T&E in general. Where appropriate for this objective, this report addresses ADS maturity shortfalls that can be used as requirements to influence future development of the technology to support T&E.

1.3.2 Schedule

JADS basic charter was granted in October 1994; the EW Test was chartered in August 1996. The JT&E program deactivates in March 2000. The program schedule for the major activities within each test program and the significant program milestones by fiscal year (FY) are shown in Figure 1. As illustrated, multiple tasks for each of the test programs were accomplished simultaneously.

³ After 1 March 2001, refer requests to the Joint Program Office Technical Library, 2001 North Beauregard St., Suite 800, Alexandria, Virginia 22311.

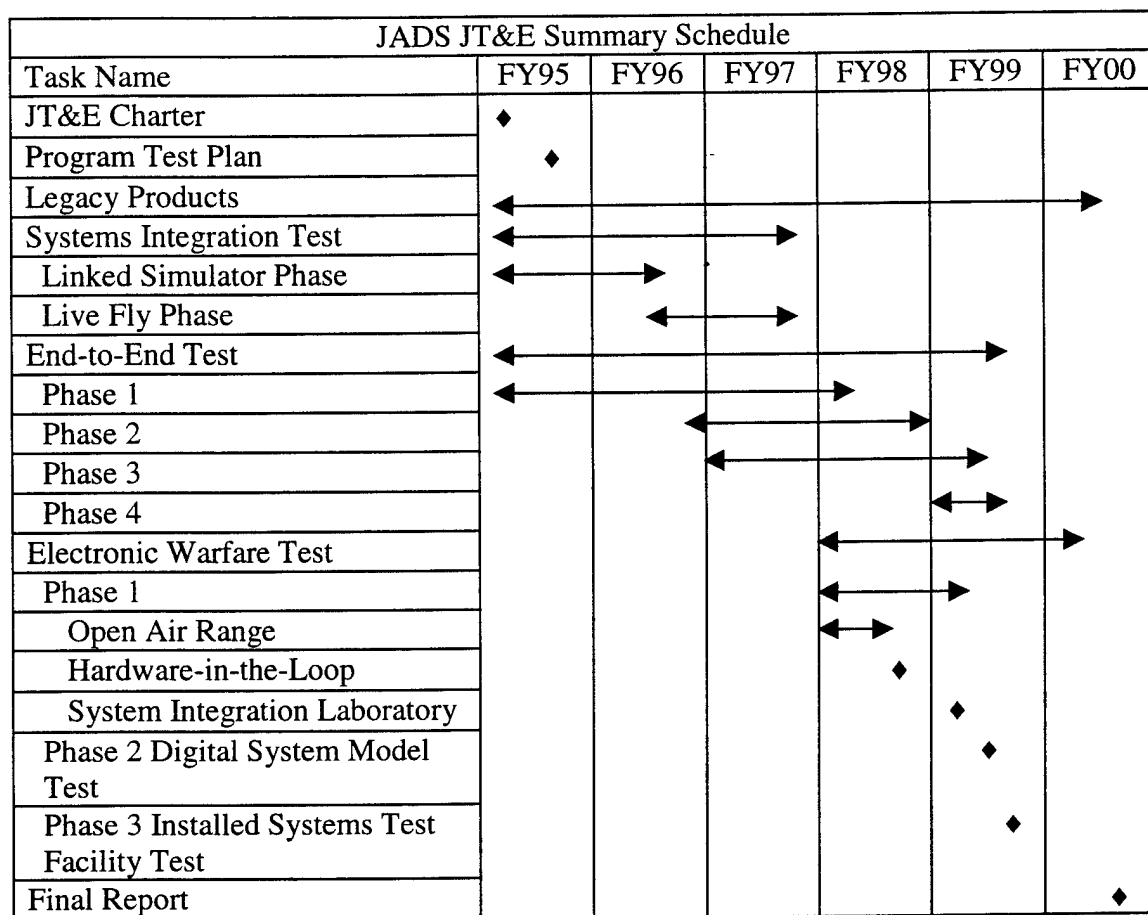


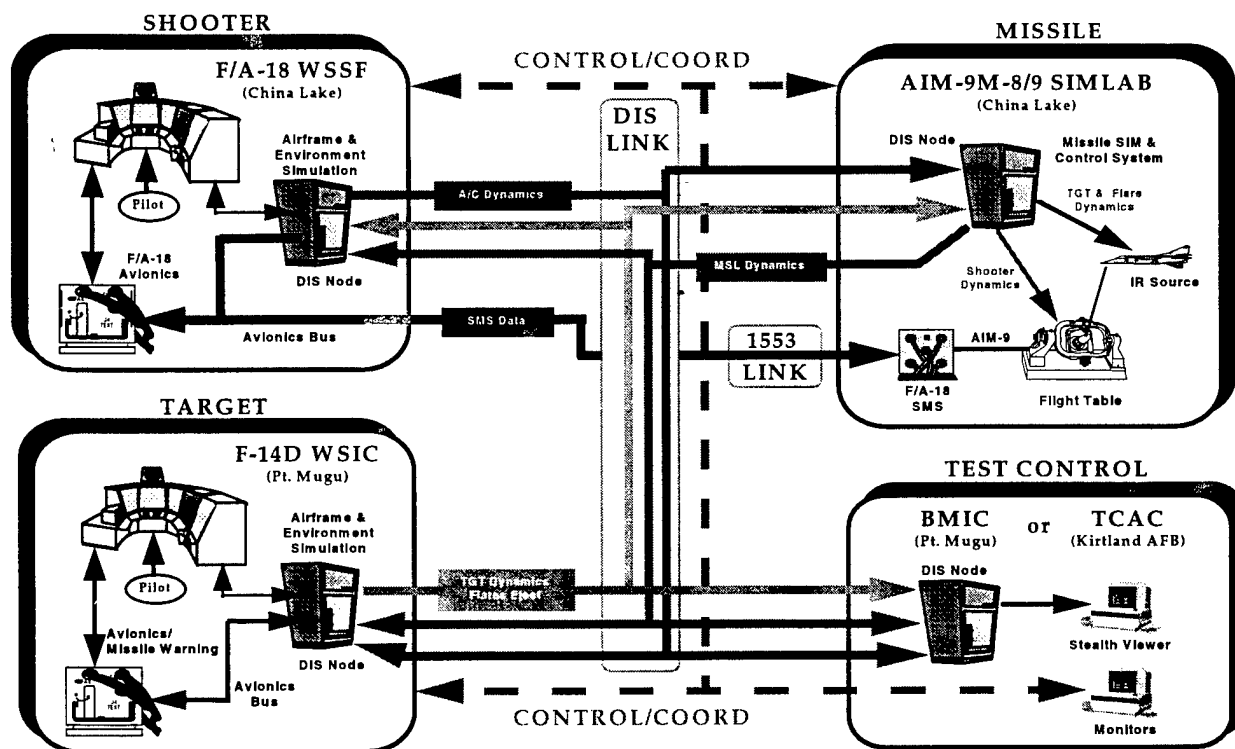
Figure 1. JADS JT&E Summary Schedule

1.4 Execution Results

This section provides an overview of each test. It includes a summary of each test, test results and conclusions, and observations for general classes of weapon systems that are based upon an extrapolation of JADS results. A detailed discussion of the results from each test can be found in the specific test's phase and final reports.

1.4.1 SIT Executive Summary

The SIT explored the ability of ADS to support air-to-air missile distributed testing. Two sequential phases, a Linked Simulators Phase (LSP) and a Live Fly Phase (LFP), incorporated one-versus-one scenarios based upon profiles flown during live test activities and limited target countermeasure capability.



A/C = aircraft
 BMIC = Battle management Interoperability Center
 SIM = simulation
 TGT = target
 WSSF = Weapon System Support Facility

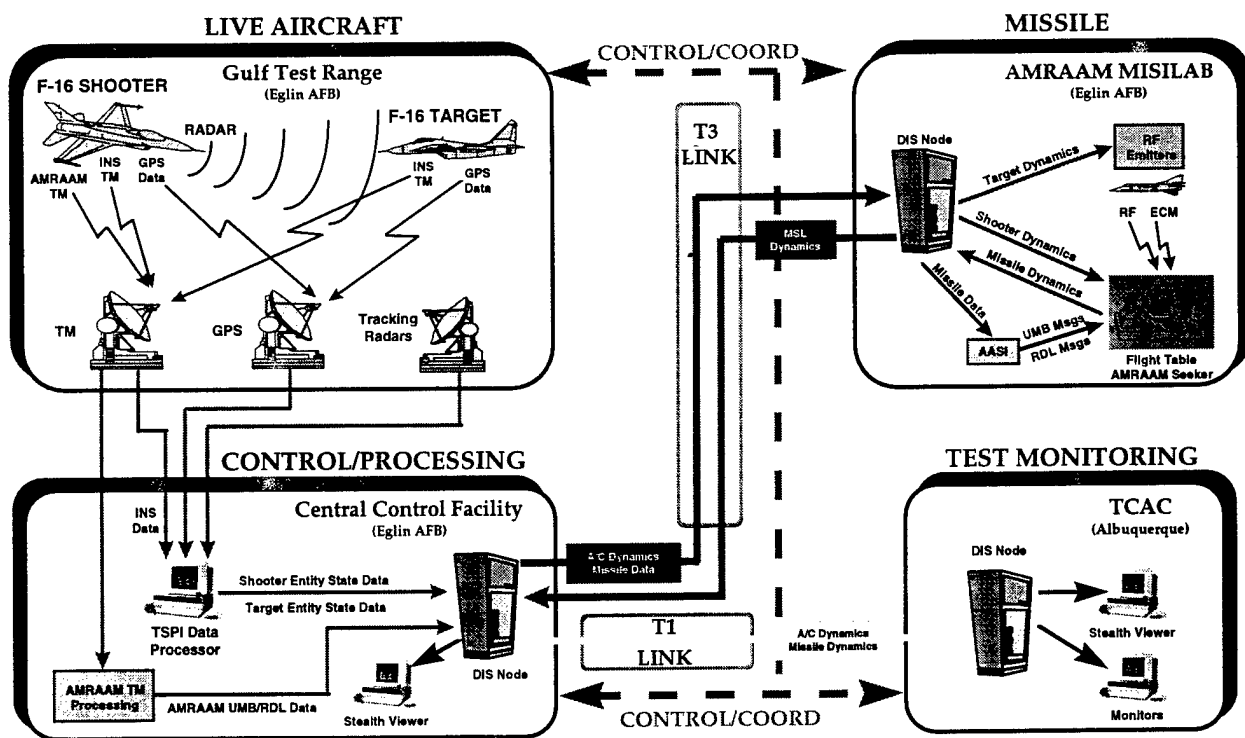
AFB = Air Force Base
 IR = infrared
 SIMLAB = Simulation Laboratory
 WSIC = Weapons System Integration Center

AIM = air intercept missile
 MSL = missile
 SMS = stores management system

Figure 2. SIT LSP Architecture

The LSP distributed architecture incorporated four nodes: the shooter, an F/A-18 manned avionics laboratory at China Lake, California; the target, an F-14 manned avionics laboratory at Point Mugu, California; a hardware-in-the-loop (HWIL) missile laboratory at China Lake that hosted an air intercept missile (AIM)-9M missile; and a test control center initially located at Point Mugu and later relocated to the JADS facility in Albuquerque, New Mexico.

The LFP distributed architecture linked two live F-16 aircraft (a shooter and target) on the Eglin Air Force Base, Florida, Gulf Test Range; the Eglin Central Control Facility; an HWIL missile laboratory at Eglin that hosted an AIM-120 missile; and a test monitoring center at the JADS facility in New Mexico.



A/C = aircraft
 AFB = Air Force Base
 ECM = electronic countermeasure
 MISILAB = Missile Simulation Laboratory
 RF = radio frequency
 T-1 = digital carrier used to transmit a formatted digital signal at 1.544 megabits per second
 T-3 = 28 T-1 lines in one; the aggregate data rate is 44.746 megabits per second
 TSPI = time-space-position information
 AASI = Advanced Aircraft Simulation Interface
 AMRAAM = advanced medium range air-to-air missile
 GPS = global positioning system
 MSL = missile
 INS = inertial navigation system
 RDL = rear data link
 TM = telemetry
 UMB = umbilical

Figure 3. SIT LFP Architecture

The following section describes the outcome of the SIT, the conclusions and lessons learned, and offers observations on the implications of SIT for the general class of precision guided munitions.

1.4.1.1 System Integration Test Results and Conclusions

Within the narrow confines of the SIT data, our assessment is that the two architectures we employed have utility for support of T&E. The JADS data indicate that activities ranging from parametric analyses to integrated weapons system testing are both practical and cost effective. Our broad conclusions and lessons learned can be summarized as follows.

- For T&E applications, the technology is not at the “plug-and-play” stage. While practical and cost effective in many cases, implementation is more challenging than many people think. Plan for a lot of rehearsals and “fix” time.
- The effects of latency and other ADS-induced errors can often (not always) be mitigated.

- Synchronization is as much a challenge as latency.
- Instrumentation and data management are challenges.
- ADS has great potential as a T&E support tool: It is a valuable addition to the tester's tool kit. ADS will not obviate, but in some cases it may reduce, the need for live testing.
- Our data suggest test savings are possible.

1.4.1.2 Observations for Precision Guided Munitions T&E

Through a process of inductive reasoning we can transfer some of the SIT-based specifics to the general class of precision guided munitions (PGM). In the general case, the elements of the SIT architectures are basic to all PGM cases. There are (1) a launch platform or shooter, (2) a PGM, (3) an intended target, (4) an operating environment (to include countermeasures), and (5) a test control center.

The shooter, PGM, and target can be represented in any of the three forms associated with distributed simulation: live, virtual, or constructive. SIT looked at an AIM-9 and an AIM-120. The physical dynamics of the problem are comparable with any class of PGM. The physics associated with detection, tracking, and guidance may differ significantly depending upon bands, techniques, and the operational medium a missile operates in. We do not see a one-for-one transfer of SIT techniques to other tests. Each test has specific requirements, often specific to the particular system under test (SUT). We do see a transfer of the principles, design processes, and methodologies used in SIT.

Countermeasures were only represented in rudimentary form in the SIT, but we see no technical impediments, at the conceptual level, to implementing high-fidelity countermeasures in distributed testing. The difficulty will be in the details, and costs and technical challenges will be very case specific. Complex environmental details associated with atmospheric, space, oceanography, etc., are more challenging. The LFP, since it involved flying open air, incorporated real atmospheric effects.

A test control center is a requirement for all testing, distributed or not. Fortunately, the SIT experience suggests that the control center can function from almost anywhere. The inference is that an existing control center somewhere may well meet a specific tester's needs.

The SIT program was budget and schedule constrained. Consequently, there were important aspects of PGM testing that SIT did not explore. From a single shooter perspective, some of these included multiple launches against a single target, single launches against clustered targets, and multiple launches against multiple targets. SIT did not examine few-on-few or many-on-many scenarios. Our expectation, unsupported by hard data, is that few-on-few implementations are possible. The difficulties and costs would be extremely sensitive to the fidelity requirements and the availability of existing facilities, e.g., HWIL facilities or installed systems test facilities.

The SIT results strongly suggest that ADS has good potential for improving PGM testing. The implication is that test planners should consider the technology as a relevant tool for their program until an objective assessment suggests otherwise. Bottom line: Know distributed testing is there, and assess how, or if, it should be used in a specific program.

1.4.2 ETE Test Executive Summary

The ETE Test evaluated the utility of ADS to support mission-level testing of C4ISR systems. The test used the Joint STARS as one component of a representative C4ISR system. Other C4ISR elements represented in the ETE Test included virtual battlefield entities (including about 10,000 threat entities), manned air and ground operator workstations, an actual Army target analysis cell, a fire direction center, and simulated missiles for attacking selected targets. Tactical communications systems were used between most of these elements. Figure 4 shows what a typical C4ISR ADS architecture might look like using a representation of the JADS ETE Test configurations.

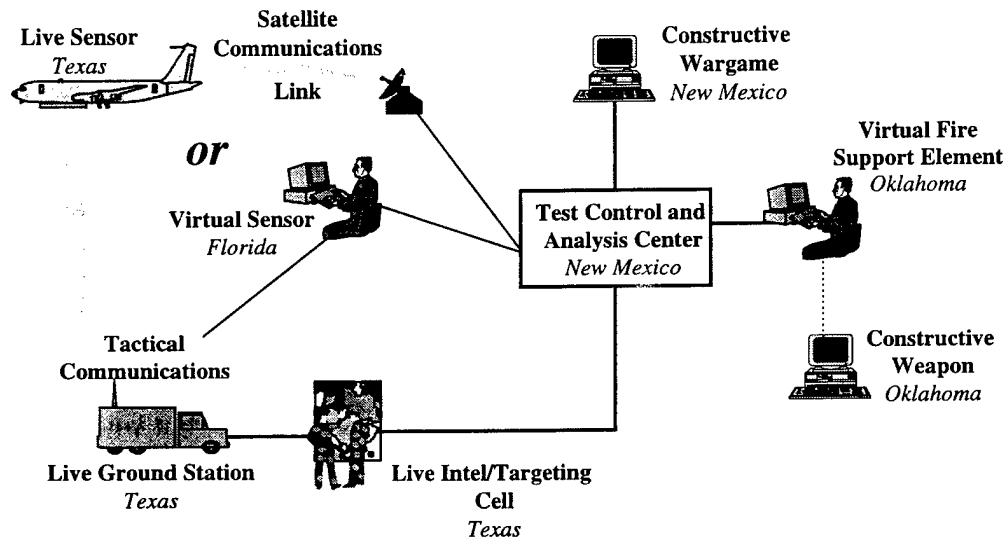


Figure 4. C4ISR ADS Architecture

There were two separate representations for the Joint STARS E-8C aircraft. In the laboratory configuration, the Virtual Surveillance Target Attack Radar System (VSTARS) radar emulation represented the E-8C radar subsystem and provided the inputs needed to drive target displays on operator workstations. In the live configuration, an actual E-8C aircraft was flown and the workstation operators observed actual live ground targets participating in an exercise along with the virtual battlefield entities.

1.4.2.1 End-to-End Test Results and Conclusions

Within the confines of the ETE Test data, our assessment is that the architecture we employed has utility for support of C4ISR T&E, especially realistic mission-level testing. The JADS data indicate that DT&E and OT&E activities incorporating ADS technology are both practical and cost effective.

- ADS often requires linkage among dissimilar facilities, network equipment, and simulations. While practical and cost effective in many cases, implementation is more challenging than many people think. Plan for a number of rehearsals and periods of “fix” time.
- ADS requirements must be clearly defined early in the test planning phase, since individual facilities are generally unfamiliar with conducting coordinated, distributed T&E tests.
- Instrumentation and data management are challenges.
- Have a centralized test control center with test controllers who are extremely familiar with the test and network configuration.
- ADS testing of C4ISR systems is technically feasible, provides valid data, and is cost effective in many cases.
- ADS has great potential as a C4ISR testing tool and provides a useable means of conducting realistic mission-level evaluations.

1.4.2.2 Observations for C4ISR T&E

Since all C4ISR systems contain the same basic elements (e.g., sensor(s), sensor platform(s), command and control elements, communication lines, and computer hardware and software), the extension of the ETE Test results to other possible C4ISR applications is relatively straightforward. ADS technology allows the evaluation of human-in-the-loop actions, decision processes, timelines, and interoperability that digital simulations do not model well. Using ADS, a mission-level scenario model can be linked to actual C4ISR hardware and software with tactical operators-in-the-loop and tactical communications links for realistic testing in force-on-force scenarios that cannot be accomplished in live testing.

A test control center is a requirement for all testing, distributed or not. Fortunately, the ETE Test experience suggests that the control center can function from almost anywhere with costs tailored to the test requirements. Thus, a specific test may save resources by using an existing control center.

ADS is not just of value to C4ISR T&E but can be applied throughout the system acquisition life cycle. In fact, the benefits of using ADS are best realized over the life of a program. ADS is an enabling technology for Simulation Based Acquisition (SBA) and the Simulation, Test and Evaluation Process (STEP) as applied to C4ISR systems, since these systems are naturally distributed by nature.

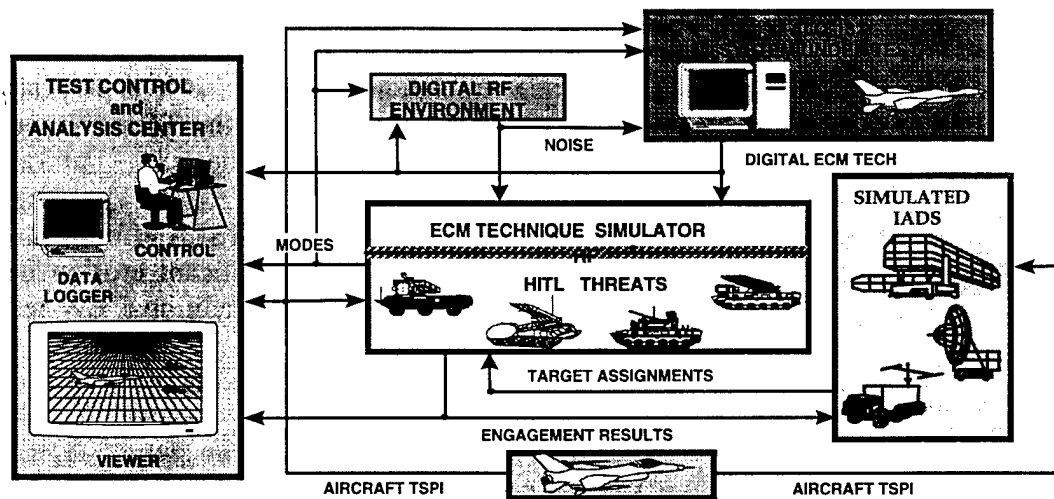
- ADS can create a cost-effective environment for test preparation to include the development of concepts of operations, refinement of test scenarios, rehearsal of test execution, and data collection and analysis.
- ADS allows the integration of models developed by different acquisition programs.

- ADS can expedite the association of results from live tests with output of simulations.
- ADS supports the execution of the Joint Vision 2010 paradigm, which requires realistic battle-space environments populated with many weapon systems and threats. In particular, ADS allows the large-scale, complex environment evaluations needed for C4ISR systems.
- ADS can support the model-test-model process by providing more realistic test results that can be used to refine digital system models.
- ADS enables the linking and integration of geographically distributed resources from different system representation domains (e.g., digital system model, hardware-in-the-loop laboratory, integrated systems test facility, open air range) that can lower testing costs.
- ADS supports experimentation of emerging war fighting concepts and testing new weapon systems.
- ADS can reduce the operations tempo (OPTEMPO) of test participants and evaluators in pretest training and integration periods as well as in the test period itself.

The ETE Test results strongly suggest that ADS has excellent potential for improving C4ISR testing and system acquisition. Test planners and program managers should consider the technology as a relevant tool for their program unless an objective assessment suggests otherwise.

1.4.3 EW Test Executive Summary

The EW Test evaluated the utility of ADS to support EW T&E. While the test used several efforts to examine distributed testing-based T&E, the cornerstone effort was a series of traditional and distributed testing-based events using an airborne self-protection jammer (SPJ). The SPJ test defined a simple, repeatable test scenario. The scenario was executed in three traditional test environments to create a data baseline. The test scenario was then executed in two ADS-enhanced test environments. The first ADS-based event used a real-time digital system model (DSM) interacting with manned threat simulators at the Air Force Electronic Warfare Environment Simulator (AFEWES) facility. The second ADS-based event used the SPJ installed on an F-16 suspended in the anechoic chamber at the Navy's Air Combat Environment Test and Evaluation Facility (ACETEF). The data from all tests were statistically compared in an attempt to quantify the impacts of ADS.



ECM = electronic countermeasures
RF = radio frequency

HITL = hardware-in-the-loop
TSPI = time-space-position information

IADS = Integrated Air Defense System

Figure 5. Electronic Warfare SPJ Test Architecture

The other efforts used by JADS to examine the utility of ADS were

- 1) the OSD CROSSBOW Committee-sponsored Threat Simulator Linking Activity (TSLA) effort,
- 2) the DMSO-sponsored High Level Architecture Engineering Protofederation (EPF) effort, and
- 3) the Army's Advanced Distributed Electronic Warfare System (ADEWS) development effort.

Each of these efforts added to the SPJ test experience to provide a broader understanding of the utility of ADS to EW T&E.

1.4.3.1 EW Test Results and Conclusions

Within the confines of the SPJ test data, JADS concluded that ADS architectures that allow the capabilities of geographically separated facilities to be combined to create a realistic test environment for EW devices can be designed. This allows the same test environment to be used for SUT representations ranging from DSMs to operational equipment. Testing in a common ADS-based environment represents a significant departure from the traditional sequential EW test process.

- ADS testing architectures requires a close team comprised of several technical experts spanning several disciplines directed by a system integrator.
- The architecture produced valid results for both the DSM and actual jammer hardware.

- Latency within the closed-loop interaction was aggressively managed, and JADS was able to meet its objective for more than 95 percent of the runs.
- HLA appears to be a feasible method for linking simulations for T&E. It is appropriate to use HLA to link to other HLA-compliant simulations/simulators, but the T&E community should not view it as the only architecture to consider in designing ADS tests.
- Two of the eleven EW testing facilities surveyed in 1996 as part of the TSLA effort that were appropriate for ADS-based events have been closed. This is a significant erosion in the infrastructure needed to design and execute ADS tests limiting the traditional EW testing process.

1.4.3.2 Observations for EW T&E

JADS assessment, based on the different EW Test efforts, is that ADS has varying levels of utility for EW T&E. These levels of utility depend on the nature of the EW device being tested and the availability of suitable test facilities. Single function EW devices and federated EW systems are expected to benefit least from a ADS-enhanced process. Only radio frequency (RF) jammers may see sufficient benefit to outweigh the additional cost of a distributed testing-enhanced test process. Integrated EW systems may see significant benefits where a single test facility is not capable of providing all the stimulation (including the closed-loop SUT versus manned threat interaction for systems that include RF jammers) needed to simultaneously test all the particular integrated EW system functions. Systems of systems testing, such as that required for electronic support (ES) systems, should see significant benefits in ADS-based events.

1.5 Other ADS

In addition to the three specific tests, JADS participated to varying degrees with other test agencies and organizations using ADS technologies. The purpose of this effort was to leverage off these other activities to broaden our conclusions concerning the utility of ADS across the entire spectrum and to narrow our focus. JADS level of involvement with other ADS organizations ranged from passive monitoring to full-scale support of test activities. Where appropriate, JADS mapped conclusions and lessons learned from various organizations onto JADS measures and objectives. A discussion of these conclusions and lessons learned is included under the relevant measures in Section 2. Table 2 lists the activities and programs JADS was involved with and characterizes our degree of involvement.

Table 2. Other ADS Activities and JADS Degree of Involvement

Activity	Description	JADS Involvement
Common Ground Station (CGS) Follow-On Operational Test and Evaluation (FOT&E)	Follow-on test and evaluation of the Army's CGS	Extensive
VSTARS Mission Crew Training System (MCTS) Prototype	Evaluation of VSTARS MCTS prototype to support and contribute to the overall mission crew training and continuation training processes	Extensive
Synthetic Environment Tactical Integration Virtual Torpedo Project (SETI-VTP)	Test of the real-time interaction of submarines operating on range with high-fidelity hardware-in-the-loop (HITL) torpedo simulations	Moderate
Project Constellation	Cooperative effort among Army test centers to link their facilities. The end state for Project Constellation is a virtual proving ground (VPG) capability	Extensive
Bradley Synthetic Environment Operational Test and Evaluation (SEOT)	Program to perform a series of test-like events in a synthetic environment (SE) in parallel with corresponding tests in a live environment to evaluate those aspects of the SE that are mature enough to support future testing and to identify and quantify areas of the SE requiring further development	Moderate
Threat Simulator Linking Activities Study (TSLA)	CROSSBOW-sponsored activity to provide the facility and network features required to support the T&E of electronic warfare systems where the test environment is composed of distributed assets	Extensive
Joint Strike Fighter (JSF)	Employment of simulated aircraft/capabilities in a simulated theater of operations for analysis of capabilities	Limited
Joint Theater Missile Defense (JTMD)	JT&E to investigate and evaluate the capability of US forces to conduct TMD attack operations employing existing systems	Limited

Activity	Description	JADS Involvement
Joint Combat Search and Rescue Joint Test and Evaluation (JCSAR JT&E)	Linked hardware-in-the-loop simulators and computer-generated forces at Theater Air Command and Control Simulation Facility (TACCSF) and Aviation Test Bed (AVTB) simulation facilities to execute JCSAR events for a rescue force launch order to recover and extract isolated personnel	Moderate
Simulation, Testing and Operations Rehearsal Model (STORM)	Test support tool for Force XXI Battle Command, Brigade and Below (FBCB ²) tests providing a combined synthetic and live test environment that replicates C4I systems and information flows for brigade-level units and below	Moderate
Combat Synthetic Test and Training Range (STTAR)	Early Joint STARS simulation that used Janus to display mixed virtual and instrumented real forces	Limited
Joint Electronic Combat Test Using Simulation (JECSIM)	Test of semi-active missile systems against multiple electronic countermeasures (ECM) techniques employed by missile, fighter and bomber-sized targets, compare results to model and simulation (M&S) predictions, and correlate between model results and live test results	Limited
Anti-Armor Advanced Technology Demonstration (A ² ATD)	Demonstration to develop a distributed synthetic environment capability to support anti-armor weapon system virtual prototyping, concept formulation, requirements definition, effectiveness evaluation and mission analysis on a combined arms battlefield at the battalion task force and brigade level	Limited
Advanced Distributed Electronic Warfare System (ADEWS)	Simulation of the effects of the R330 jammer on friendly communication equipment including the Single-Channel Ground and Airborne Radio System (SINCGARS) radio	Extensive

2.0 Analysis of Test Objectives

2.1 Utility

To determine the utility of ADS to T&E, JADS assessed the validity of data from tests using ADS, as well as the cost effectiveness and other benefits of using ADS. ADS has utility if performance data compare favorably to reference data and if ADS data are timely, accurate, reliable, correct and otherwise represent real-world systems data. The first step in the analysis process was to determine if and, where possible, to what degree ADS provides valid data. The first objective of the first JADS issue addressed data validity. The second objective related to the cost effectiveness and benefits of using distributed testing.

Issue	Objectives
Issue 1: What is the present utility of ADS, including DIS, for T&E?	Objective 1-1: Assess the validity of data from tests using ADS, including DIS, during test execution Objective 1-2: Assess the benefits of using ADS, including DIS, in T&E

2.1.1 Data Validity from Tests Utilizing ADS

To determine data validity the JADS a priori approach was to take a previously executed live test, replicate that test in an ADS environment and compare the results. The assumption was that live data were by definition valid or "truth". This approach proved problematic and more complicated than anticipated. Live data are often incomplete, either because of missing environmental information or inadequate instrumentation. Live data are also subject to measurement errors that may or may not be well documented. The fact that live test data are generally only available in a very small number of scenarios is another limiting factor in a comparison approach to data validation. Because of the uncertainties and complications associated with live data, it was not always obvious that live data rather than lab data should be the assumed "truth." Because of these uncertainties and complications associated with using live data as baseline truth JADS used additional means of determining ADS data validity.

In addition to, or sometimes in lieu of, comparing an ADS test to a previously executed live test, JADS used other analysis techniques to determine data validity. These techniques included manual and automated consistency checking, analysis of summary statistics, outlier analysis, subject matter expert (SME) analysis and measure of effectiveness (MOE)/measure of performance (MOP) analysis. These techniques either supplemented or, in some instances, replaced ADS data comparisons to live data to determine ADS data validity. The specific techniques to determine data validity used by each of the three JADS tests are discussed in detail in the individual test phase and final reports. In all cases ADS data were valid.

2.1.2 Benefits of Using ADS for T&E

The structure of an optimal testing program should be based on the appropriate balance between cost savings and benefits. To determine the benefits of any new capability or technology there must be objective standards against which the performance of the new capability or technology is measured. These performance measures or standards can be both quantitative and qualitative. This report categorizes performance or effectiveness measures as either standards related to enhanced testing capability (is it better or faster?) or to standards related to cost reduction potential (is it cheaper?).

2.1.2.1 Enhanced Test Capability

JADS demonstrated that ADS could overcome many of the traditional limitations and problems with test and evaluation. ADS allows a richer more reactive environment to be created earlier in system development. Traditional single model or model-versus-model analysis is not as reactive as simulations where human intelligence is allowed to affect appropriate system actions. Human operators are an integral part of many weapons systems and need to be part of early system testing if possible. For example, using models to determine jammer effectiveness against manned threats ignores the human operator's ability to recognize the target in the jammed display increasing the risk that the jammer will be ineffective. By allowing the digital model to interact with the manned threat simulators, ADS allows the system developer to reduce the development risk by measuring jammer effectiveness early on. In the PGM example, linked laboratories can provide reproducible, higher confidence results. Missile testing using a linked laboratory distributed testing architecture is more reproducible than live testing, because scenario conditions are more readily controlled and trials can be replayed for additional PGM responses. This allows more trials to be combined for analysis, giving greater confidence in evaluation results. ADS also injects more realism than analytical models since actual hardware is used and linked simulation is often more realistic than stand-alone HWIL laboratories. ADS allows the test designer to take advantage of the laboratories inherent abilities to provide secure evaluation of classified electronic countermeasures (ECM) techniques and increase force density or representation through the use of simulation. In the C4ISR arena, ADS allows the force density of the scenario to be increased affordably. The number of friendly and threat systems can be increased by representing them with either manned laboratories (if realistic man-in-the-loop control of the systems is needed) or DSMs (if scripted behavior is acceptable). The inability to evaluate system performance in combat-representative environments is a common limitation in OT&E and an area in which ADS can improve the operational test (OT) environment. The ability of ADS to create affordable, large-scale and complex environments for the SUT could mean more thorough testing. That, in turn, could provide early identification of problems that might otherwise go unnoticed. There is also a potential for reducing test duration by using multiple facilities in an integrated environment rather than using them sequentially.

JADS found enhanced test capability for ADS in each of the areas investigated. Key areas of utility are discussed further in the *JADS Special Report on the Cost and Benefits of Distributed Testing* which can be found at www.jads.abq.com.⁴

2.1.2.2 Cost Reducing Potential

Another way of categorizing the benefits of using ADS relates to the cost reducing potential. The use of ADS may directly result in cost savings and/or reduce overall program costs by avoiding costs.

A live test that requires multiple platforms be brought to and assembled at a test range is one example of the type of test that, for some cases, would be more efficiently and effectively accomplished with ADS testing. This example could at least help support the argument for a reduction in the number of expensive live tests required. Software (SW) developed for ADS may be reused to support traditional testing methods. One example of this is from the JADS System Integration Test, Live Fly Phase. The special purpose interface developed to connect aircraft to the Advanced Medium Range Air-to-Air Missile (AMRAAM) Ground Lab was later used for troubleshooting in traditional testing methods. VSTARS is probably the best example of SW developed for ADS with reuse capability. However, more than software fits in this category. For example, AFEWES manned simulators were used for decades in traditional T&E. They were used by JADS for ADS-based testing by adding an interface to the facility. Any potential overlap between traditional and ADS methods should be addressed by feasibility analysis.

The empirical data from the JADS tests have provided the JTF, already experienced in conventional T&E techniques, with sufficient confidence to identify benefits and savings arising from the use of ADS. Several uses for ADS testing technologies have been identified that support cost savings for traditional tests and across the program that should be considered when assessing the cost of ADS to the overall program.

- ADS test analysis results can indicate where live testing can best be focused and may reduce the need for some live tests.
- ADS results in a synthetic environment (SE) that can support other areas of the program, other programs, and other DoD initiatives. For example:
 - The SE capability supports system design and development, training simulation, and training for the live test community.
 - It can be used for early operational assessments, development of tactics, techniques and procedures before system testing, test rehearsal, verification of data sources and data reduction techniques, and to determine whether adequate data are collected to evaluate test measures.

⁴ After 1 March 2001, refer requests to the Joint Program Office Technical Library, 2001 North Beauregard St., Suite 800, Alexandria, Virginia 22311.

- In some cases, other test programs that require similar input can reuse an SE (e.g., the ETE Test SE, with minor upgrades, could be reused for the Block 2 Army Tactical Missile System (ATACMS) OT&E).

The SBA and STEP initiatives will advance more quickly as programs initiate development of SEs as a normal step in the program's life cycle. The focus of SBA is reduced cycle time -- the ability to use the technology to develop systems more rapidly, reducing the current major system cycle time from 15-20 years to 7-10 years (50 percent). Currently, most systems progress through a series of sequential tests at multiple facilities using the unique capabilities of the individual facilities to address different test objectives. Distributed testing using ADS technologies can be used to link the individual facilities and conduct concurrent testing of multiple test objectives, thus providing the opportunity for significant time and cost savings. If shortening the acquisition timeline results in cost savings, then there is a powerful argument for using the technology. Major test programs often employ a variety of tools including physical models, force-on-force models, hardware-in-the-loop (HITL) facilities, open air testing, system integration labs, simulators, measurement facilities and the like. In some cases, testers take advantage of large-scale field exercises (which are becoming increasingly rare). In many cases, the SUT must be moved from facility to facility in a sequential stream. Because of scheduling issues with high use facilities, there is often a significant amount of slack in test program time lines. Where large-scale field exercises are the test vehicle of choice, there may be a year or more between test opportunities. Additionally, the use of ADS can reduce total testing costs by replacing a limited number of live tests with ADS-based events.

Cost avoidance is the notion that ADS can help perform more complete testing earlier in a program, identifying failure modes and other problems earlier when they can be fixed cheaper and faster than when they are discovered later in the system's life cycle. For example, the ability of ADS to incorporate man-in-the-loop provides an opportunity for cost avoidance when the technology is used as a test rehearsal and training tool. Test participants can climb the early part of the learning curve in the virtual environment, and the test schemes can be refined prior to the use of very expensive test facilities. The time associated with lost test events could therefore be reduced. In some situations, ADS can reduce the risk and cost of wasted live fire attempts by providing a realistic test rehearsal capability. More thorough testing should result in identification of system deficiencies earlier in the life cycle when they can be fixed more efficiently saving schedule and dollars. ADS can redo live tests that have encountered problems more quickly than live retesting which would result in schedule slips. Traditional tests are still required, but by reducing the number of lost test events one could save money overall.

Testing could be more thorough, complete more test scenarios, and used for cases where live tests are limited by test range constraints, weather, equipment, or when the test environment needs to be very complex. For example, the Joint STARS Multiservice Operational Test and Evaluation (MOT&E) was originally planned to be conducted over the National Training Center at Fort Irwin, California, with 300-500 military vehicles in the maneuver area. Background traffic from Los Angeles, California, and Interstate 10 would have provided a more operational load on the system, however, would not have provided an increased load on the operators. This approach was taken because the test planners realized they would never be able to provide an operationally representative test environment short of an actual war. The JADS ETE Test was

able to represent 10,000 vehicles arranged and maneuvering in a doctrinally correct threat laydown of enemy corps. This provided a much more representative operational environment to perform OT and provided the testers with a repeatable environment where ground truth was known.

2.1.2.3 Capability to Support Early Stages of the Acquisition Process

The DoD is seeking to streamline the acquisition process by the use of simulation technology through a strategy called Simulation Based Acquisition. The goals of SBA are to

- substantially reduce the time, resources, and risk associated with the entire acquisition process,
- increase the quality, military worth, and supportability of fielded systems while reducing total ownership costs throughout the total life cycle, and
- enable integrated product and process development across the entire acquisition life cycle.

A key element of SBA is the STEP, which is defined as “an iterative process that integrates simulation and test for the purpose of interactively evaluating and improving the design, performance, joint military worth, survivability, suitability, and effectiveness of systems to be acquired and improving how those systems are used.”

Under the SBA and STEP concepts, the cost of testing is reduced because investments in simulations in early acquisition phases can be leveraged rather than duplicated in later stages. Reliability is increased because of the iterative approach inherent to SBA and STEP where results from field tests are incorporated back into models in a model-test-model paradigm. Overall cost of acquisition is reduced because system evaluators can merge information from multiple acquisition phases maximizing insight to system performance.

ADS is particularly useful in supporting SBA. ADS has relevance in these areas.⁵

- ADS can provide a framework for the integration of models developed by different acquisition programs, since the use of ADS techniques (e.g., linking via network interfaces and data protocols) can permit disparate simulations to be linked, as demonstrated during JADS testing.
- ADS can expedite the association of results from live tests of a C4ISR element with the output of simulations of the element. Using the same approach as the ETE Test, the element can either be represented by the actual hardware or by a simulation and linked in either case to the same representations of the other elements of the C4ISR system. Since the same scenarios and synthetic environment can be used, correlation of results between the live element test and the element simulation is relatively straightforward and can support the model-test-model process at the element level.

⁵ The assessments in this section are extrapolations of the results of JADS testing and related distributed testing programs and are based on JADS experience and insight.

- ADS can also support the model-test-model process at the system of systems level by providing more realistic mission-level test results that can be used to refine digital system models for the entire C4ISR system.
- ADS supports the execution of the Joint Vision 2010 paradigm that requires realistic battlespace environments populated with many weapon systems and threats. In particular, ADS allows the large-scale, complex environment evaluations needed for C4ISR systems.
- ADS enables the linking and integration of geographically distributed resources from different system representation domains (e.g., DSM, HITL lab, ISTF, battle labs, open air range [OAR]) that can lower test costs.
- ADS supports experimentation of emerging war fighting concepts and testing new weapon systems.

Further, ADS techniques can be applied to all C4ISR element acquisition phases.

- Concept Exploration. If a C4ISR element DSM becomes available during this initial system acquisition phase, ADS linking techniques can be used to provide a more realistic battlefield environment and to permit human interactions with the simulated element. This capability is especially useful for development of a concept of operation (CONOPS) for the emerging element system.
- Program Definition and Risk Reduction. As prototype C4ISR element system hardware is developed, ADS-based testing can be expanded and refined. ADS configurations can be used to support early operational assessments and for more realistic specification compliance testing during DT&E.
- Engineering and Manufacturing Development. Mission-level evaluations have replaced traditional requirements-based OT&E to determine whether the system supports the warfighter and ADS-based testing is well suited for this application. By using ADS, the C4ISR system can be placed in a realistic operational environment and valid data can be collected for the evaluation of operational measures.
- Production, Fielding/Deployment and Operational Support. By permitting operator-in-the-loop operations with tactical hardware, ADS can support the development of tactics and operational procedures in conjunction with realistic training. ADS can also be used for the development of integrated logistics concepts.

ADS is also useful for supporting the iterative spiral development process. As the C4ISR element undergoes improvements and upgrades, ADS can be used to more realistically

- verify the element system design,
- confirm that design risks have been controlled,
- certify readiness for operational testing, and
- evaluate the system's operational effectiveness, suitability, and survivability.

2.1.2.4 Capability to Support T&E Planning and Test Rehearsal

Although ADS technology, in and of itself, does not help to support traditional test planning and rehearsal, incorporating aspects of ADS into tests can impact planning and rehearsal in several areas including facilitating test concept and design, tactics development, and test preparation. ADS possesses great potential for making improvements in these areas; yet, there is sometimes a price to be paid for the added flexibility and complexity that accompanies these improvements. The following paragraphs highlight both the additional value and complexity involved in T&E planning and test rehearsal using ADS, as experienced during the three JADS test efforts.

ADS offers great potential for improving test concept and test design, as demonstrated by the impact of its use in the ETE Test. The original Joint STARS operational test plan covered only a small subset of its capability. With the creation of VSTARS, a virtual model of Joint STARS, and the inclusion of ADS to the test concept and test design, JADS demonstrated that a far more complex and credible test could be planned, rehearsed, and performed to test the Joint STARS/VSTARS capabilities. Without the use of ADS, operational test designs for systems like Joint STARS may remain limited in scope and complexity.

Similarly, the JADS EW Test showed that flexibility and complexity could be easily added to a test concept and design by utilizing ADS technology. Just prior to executing Phase 3, an additional simulated threat capability belonging to one of the linked facilities was added to address the impacts of system loading on both network and SUT capabilities. The HITL threats at one facility and the simulated threats from another were merged into a common environment to provide a more robust test for the SUT. The test demonstrated that ADS, in allowing for the combination of test resources from multiple facilities and the addition of assets late in the game, offers flexibility and complexity for test planning, design, and execution in the test environment.

The SIT LSP was another example of flexibility that enhanced test planning. ADS allowed the LSP to use an asset that included a man-in-the-loop instead of a constructive simulation. ADS linking provided for the use of the F-14 simulator at Point Mugu, California, operated by an operational pilot. The addition of assets that more closely represented real-world conditions enhanced test execution. With the increasing complexity and interoperability of weapon systems, it is less likely that all the assets required for a robust test will be located at a single site. ADS allows test planners to consider test designs that include the linking of assets required to support quality testing.

Using ADS can reduce the complexity of other tasks associated with testing, such as data retrieval and reduction, which, in turn, reduce the amount of test planning and rehearsal required to coordinate such efforts. For the ETE and EW tests, data retrieval and reduction procedures for ADS phases were much simpler than those used in non-ADS tests or test phases. The ETE Test data retrieval and reduction procedures were facilitated by the dedicated network connections at all test locations that allowed for easy transfer and analysis of data from all sites. Similarly, for the EW Test, the network connections to the participating test agencies in Phases 2 and 3 allowed data to be transferred more simply and accurately than for the Phase 1 OAR and HITL tests. EW Test data reduction was also simplified because each distributed testing-based test

relied on just one data file for collecting, transferring, and manipulating SUT performance data. The OAR and HITL test phases used two to ten separate files to provide the same information.

In some cases, adding flexibility and complexity to test concept and test design by distributing the test also adds complexity to the test procedures by calling for more coordination among test agencies. For the ETE Test, coordination among different test agencies became the largest obstacle in successful test execution. For the EW Test, coordination of the HLA architecture and configuration management were more difficult to manage than non-ADS tests. The SIT experienced similar issues with the added complexity of coordinating test design, test execution, and test control among agencies spread across the United States.

ADS also impacts the cost of test concept and test design. The price of added complexity and flexibility is no small consideration. The implementation of the network for the EW Test was the single most impacting task in preparing for the tests. Once these networks are established, however, the complexity of test design and test execution can be greatly decreased and costs reduced for subsequent test events. The ETE Test had different experiences in the implementation of the ADS-based events. For the ETE Test, the network was established, but the coordination among test agencies was still a major issue in successful test execution.

The SIT experiences were similar to those of the EW Test. The integration efforts required to establish the overall network were extensive. Once the integration efforts were accomplished, ADS allowed for the refinement of the test execution in a near real-time manner. This flexibility allowed for changes to be made quickly resulting in the test objectives being met.

The complexities facing the JADS JTF may well be lessened for future testers who use ADS. Work on the T&E infrastructure and on integration approaches such as HLA may ease the difficulties of design and implementation.

2.1.2.5 Capability to Overcome T&E Shortfalls

During the feasibility study prior to the JADS JT&E, a survey of existing conventional development and operational test limitations was conducted. Three hundred and sixty-one total limitations were extracted from test reports and T&E master plans. Of the 361 T&E shortfalls identified during the Joint Feasibility Study (JFS), it was determined that the results of the JTE could be extended to address the utility of using ADS T&E methodologies to satisfy 276 of those (76%). Those 276 were sorted into 40 categories as shown in Table 3. Table 3 rank orders the 40 categories according to the number of times a given shortfall was found during the T&E requirements survey.

Table 3. T&E Shortfalls Addressed by JT&E

SHORTFALL	No. ^a	METHOD ^b
Insufficient test articles	25	1,2
Electronic combat not allowed or limited/restricted	21	1
Performance restrictions	20	2
Insufficient battlespace	19	7,8
Inadequate instrumentation	18	1,2,5,7,8
Inadequate quantity and types of threat systems	17	1
Lack of systems for interoperability testing	16	1
Improper threats used	14	1,4
Insufficient number of test events	11	2
Ordnance/chaff/flare restrictions	10	7
Inadequate quantity and types of targets/drones	8	1
Lack of systems for compatibility evaluation	8	1
Human interaction not represented in simulation	8	4
Inadequate quantity and types of friendly systems	7	1
Non-production representative test assets	7	2
Test area time/availability restrictions	7	2
Non-representative force levels	6	1
Poor fidelity of mod/sim used for testing	5	1
Constrained concept of operations	4	2,8
Inability of mod/sim to replicate events/entities	3	1
Multi-dimensional threat lacking	3	1
Electromagnetic environment not representative	3	1
Poor fidelity of emulators/simulators used as targets/threats	3	1
Incorrect techniques/procedures used	3	5
Unrealistic test scenarios	3	5
Data collection from mod/sim results difficult	3	5
Security restrictions	3	7

^aNo.: Number of times shortfall was found during T&E requirements survey

^bMETHOD: Applicable ADS T&E Methodology:

- 1: Add Assets
- 2: Increase Test Length, Events, Repetitions
- 3: Real-Time Endgame Analysis/Damage Assessment
- 4: Human Factors/Live Response
- 5: Test Planning
- 6: System Development
- 7: Robustness of the Physical Environment
- 8: End-To-End Testing and/or Post-Test Evaluation

Table 3. T&E Shortfalls Addressed by JT&E (cont.)

SHORTFALL	No. ^a	METHOD ^b
Inadequate number of simulation entities	2	1
Insufficient test resources (supplies)	2	1
Indirect fire tactics and capabilities not well represented	2	1
Joint/combined operations lacking or improperly represented	2	1
Real-time instrumentation lacking	2	1
Target control lacking	2	1
Real-time analysis lacking	2	3
Incompatibility of collected data	2	5
Insufficient personnel resources	1	1
Mod/sim inflexible	1	1
Environmental impact restrictions	1	1,7
Improper friend, foe, and neutral tactics	1	5
Integrated avionics difficult to test	1	6
TOTAL	276	

^aNo.: Number of times shortfall was found during T&E requirements survey

^bMETHOD: Applicable ADS T&E Methodology:

- 1: Add Assets
- 2: Increase Test Length, Events, Repetitions
- 3: Real-Time Endgame Analysis/Damage Assessment
- 4: Human Factors/Live Response
- 5: Test Planning
- 6: System Development
- 7: Robustness of the Physical Environment
- 8: End-To-End Testing and/or Post-Test Evaluation

The remaining 85 shortfalls which were not addressed by the JT&E are listed in Table 4. Of these:

- 18 shortfalls (NOTE #1 in Table 4.) could have been addressed by specialized application of ADS T&E methodologies, but were not addressed because of scoping limitations.
- 46 shortfalls (NOTE #2 in Table 4.) could not be addressed because of inadequate environmental representations in state of the art models and simulations, a current technology limitation.
- 21 shortfalls (NOTE #3 in Table 4.) could not be addressed by applications of ADS methodologies. The use of ADS cannot overcome the fact that some VV&A may be difficult and costly; however, this fact doesn't prevent the application of ADS. If costly V&V or model development are issues, they are scoping limitations as opposed to application limitations. Additionally, it was JADS experience that the costs of model development and VV&A are manageable.

Table 4. T&E Shortfalls Not Addressed by JT&E

SHORTFALL	No. ^a	METHOD ^b	NOTE ^d
Limited training in use of test articles	14	5	1
Inadequate cluster munitions representation in models	2	1	1
Insufficient logistical support for test assets	2	2	1
Non-representation of battlespace	15	7	2
Non-operational environmental test conditions	13	7	2
Restrictions on laser/emp use	9	7	2
Environmental restrictions	8	7	2
Terrain modification not allowed	1	7	2
VV&A difficult and costly	9	None ^c	3
Mod/sim costly	3	None ^c	3
Misc	9	None ^c	3
TOTAL	85		

^aNo.: Number of times shortfall was found during T&E requirements survey

^bMETHOD: Applicable ADS T&E Methodology (see Table 3.)

^cNone: ADS T&E Methodologies cannot correct these shortfalls

^dNOTE: See text for explanation

We conclude that 294 of the 361 shortfalls could have been addressed in the JT&E with current or near-term ADS technology, and 276 of these were addressed (94% of those that could be addressed). Hence the JADS results have broad applicability.

The 40 shortfall categories listed in Table 3 map to JADS *Issue 1, Objective 1-2, Subobjective 1-2-3, Assess ADS capability to support T&E execution, Measures 1 through 40*. Table 5 identifies the section(s) of the final report in which these 40 measures are addressed.

Table 5. Final Report Section Addressing T&E Shortfall Categories

Final Report Section	JADS Measure
2.1.2.5.1	1-2-3-1 Degree to which ADS can add assets to test execution
	1-2-3-4 Degree to which ADS overcomes the traditional T&E shortfall of insufficient battlespace
	1-2-3-15 Degree to which ADS can provide non-production representative test assets
	1-2-3-17 Degree to which ADS can provide for more representative force levels
	1-2-3-19 Degree to which ADS can improve upon a constrained concept of operations
	1-2-3-25 Degree to which ADS can insure realistic test scenarios
	1-2-3-28 Degree to which ADS can increase the number of simulation entities
	1-2-3-29 Degree to which ADS can add resources (supplies)
	1-2-3-39 Degree to which ADS can facilitate the proper use of friend, foe, and neutral tactics
2.1.2.5.2	1-2-3-9 Degree to which ADS increases the number of test events
	1-2-3-16 Degree to which ADS can overcome test area time/availability restrictions
2.1.2.5.3	1-2-3-13 Degree to which ADS can represent human interaction in simulation
	1-2-3-36 Degree to which ADS can increase personnel resources
2.1.2.5.4	1-2-3-2 Degree to which ADS allows for electronic combat
	1-2-3-3 Degree to which ADS overcomes performance restrictions
	1-2-3-10 Degree to which ADS can overcome ordinance/chaff/flare restrictions
	1-2-3-22 Degree to which ADS can provide for representative electromagnetic environments
	1-2-3-27 Degree to which ADS can overcome traditional testing constraints imposed because of security restrictions
	1-2-3-38 Degree to which ADS can overcome environmental impact restrictions
2.1.2.5.5	1-2-3-7 Degree to which ADS overcomes the lack of systems for interoperability testing associated with traditional T&E
	1-2-3-12 Degree to which ADS can increase the number of systems for compatibility evaluation
2.1.2.5.6	1-2-3-24 Degree to which ADS can insure that correct techniques and procedures are used
	1-2-3-33 Degree to which ADS can provide for target control
	1-2-3-39 Degree to which ADS can facilitate the proper use of friend, foe, and neutral tactics

Table 5. Final Report Section Addressing T&E Shortfall Categories (cont.)

Final Report Section	JADS Measure
2.1.2.5.7	1-2-3-30 Degree to which ADS can represent indirect fire tactics and capabilities
2.1.2.5.8	1-2-3-6 Degree to which ADS overcomes traditional T&E shortfall of inadequate quantity and types of threat systems
	1-2-3-8 Degree to which ADS overcomes the use of improper threats used in traditional T&E
	1-2-3-11 Degree to which ADS overcomes the traditional T&E shortfall of inadequate quantity and types of targets/drones
	1-2-3-14 Degree to which ADS can provide adequate quantities and types of friendly systems
	1-2-3-21 Degree to which ADS can provide multidimensional threats
	1-2-3-39 Degree to which ADS can facilitate the proper use of friend, foe, and neutral tactics
2.1.2.5.9	1-2-3-40 Degree to which ADS can test integrated avionics
2.1.2.5.10	1-2-3-18 Degree to which ADS can provide for improved mod/sim used for testing
	1-2-3-20 Degree to which ADS can overcome mod/sim's inability to replicate events/entities
	1-2-3-23 Degree to which ADS can provide high fidelity emulators and simulators used as targets and/or threats
	1-2-3-26 Degree to which ADS can facilitate mod/sim data collection
	1-2-3-37 Degree to which ADS can overcome mod/sim inflexibility
2.1.2.5.11	1-2-3-31 Degree to which ADS can represent joint/combined operations and capabilities
2.1.2.5.12, also 2.2.1 – 2.2.2	1-2-3-34 Degree to which ADS can provide for real-time analysis
	1-2-3-35 Degree to which ADS can overcome incompatibility of collected data
2.1.2.5.13, also 2.2.1.1	1-2-3-5 Degree to which ADS overcomes traditional T&E shortfall of inadequate instrumentation
	1-2-3-32 Degree to which ADS can provide for real-time instrumentation

2.1.2.5.1 Ability of ADS to Increase Assets, Force Levels, Entities, and Battlespace

This section addresses the following JADS measures:

JADS Measure 1-2-3-1 Degree to which ADS can add assets to test execution

JADS Measure 1-2-3-4 Degree to which ADS overcomes the traditional T&E shortfall of insufficient battlespace

JADS Measure 1-2-3-15 Degree to which ADS can provide for non-production representative test assets

JADS Measure 1-2-3-17 Degree to which ADS can provide for more representative force levels

JADS Measure 1-2-3-19 Degree to which ADS can provide improve upon a constrained concept of operations

JADS Measure 1-2-3-25 Degree to which ADS can insure realistic test scenarios

JADS Measure 1-2-3-28 Degree to which ADS can increase the number of simulation entities

JADS Measure 1-2-3-29 Degree to which ADS can add resources (supplies)

JADS Measure 1-2-3-39 Degree to which ADS can facilitate the proper use of friend, foe, and neutral tactics

Conventional T&E is commonly limited by battlespace restrictions and an inadequate number of entities. Typical tests are often conducted in conjunction with training missions in order to acquire a suitable battlespace and a large number of assets. If testers rely on training missions, they have only minimal control over test specifics and their test must be limited to the training scenario being executed. ADS allows testers to overcome this T&E shortfall by providing a affordable larger battlespace with a mix of live and virtual assets, reducing the number of personnel and equipment needed for the test.

The size of the battlespace and number of entities were primary issues for the ETE Test. The ETE Test was executed using nearly 10,000 Janus entities for each vignette and a virtual battlespace of 150 square kilometers (km²). It would be impractical for a typical test to be conducted with such a large number of entities and battlespace because of the cost and logistics involved, even if the test was conducted in conjunction with a training mission.

For the ETE Test, the battlespace and large number of entities gave the test team the ability to closely reflect the number and types of forces expected of an Army corps functioning in an operational theater. The testers were also able to control specific aspects of interest in the scenarios and to expand the test concept and design as desired. The largest tests conducted by

the Army, comparable to the scenarios tested by the ETE Test team, are accomplished at the National Training Center (NTC). These tests are executed in conjunction with NTC using a maximum battlespace of about 100 km². The results show the great increase in battlespace exhibited by the Phase 4 test over traditional testing where an additional 50 km² were added to the battlespace. In addition, the battlespace of 150 km² used by the ETE Test team is far from the maximum that ADS is capable of supporting. This battlespace was picked for its applicability to the scenarios used during the Phase 4 test, but could be greatly expanded if necessary. In addition, using ADS technology, even larger numbers of entities and more battlespace could have been added. The Phase 4 ETE results imply the following benefits of ADS-based testing:

- An ADS-enhanced live test environment using validated simulations can provide more realistic threats and force levels than those offered by conventional tests, i.e., threats/force levels otherwise unavailable because of cost restrictions, unobtainable threats, etc.
- C4ISR system testers can tailor the simulation entities operating in the ADS environment to closely reflect the forces expected in operational theaters, thus further increasing the relevance of the collected test data.
- ADS allows testers to have more control over the specific aspects of the scenarios of interest and to expand their test concept and design. A typical constraint to test concept development is the number and types of units readily available for a test. For example, a conventional test may require the use of a battalion, but because of a prior commitment or cost these personnel may not be available. In contrast, ADS allows testers to create a virtual battalion and to test their concepts with a minimum number of personnel and equipment.

To a lesser extent, the EW Test also offered the ability to increase the number of threats and targets available. For the EW Test, the ADS technology made it possible to add as many simulated threats to the engagement as there were RF generators at the test facility, adding unmanned threats to the scenario to go along with the manned threats used at AFEWES. Similarly, the EW Test could increase the number of targets easier than in a traditional test. Through script manipulation, multiple targets could be added to test the reactions of the normal threats to multiple targets.

The size of the battlespace, and the number of entities were not issues for the SIT because of the scenarios being simulated. However, though the SIT used only a few entities during testing efforts, the architecture would have allowed for the addition of other entities if they had been required.

With traditional testing it is often difficult and expensive to acquire all the support resources and supplies to conduct a robust test. Most applications of ADS supported distributed testing can be used to overcome a shortage or lack of test resources (supplies) typical of most forms of traditional testing. EW testing on the other hand, unlike other forms of traditional testing, uses few, if any, expendable resources such as supplies. Therefore, there is little if any need to use ADS in EW testing to overcome a shortage of supplies.

Although ADS can be used to overcome a shortage of supplies there are test resources unique to the use of ADS. The test resources (supplies) involved in the setup and execution of the ETE test were examined to determine which resources would not have been required for a traditional test. In addition, the amount of resources (supplies) required for the test, due solely to ADS-specific requirements, was documented. ADS tests, unlike traditional tests, require resources (supplies) related to the network and distributed nodes. Additional network and communication equipment is needed to ensure network reliability and good communication at all nodes. In addition, an increased amount of computer equipment is required at the distributed nodes to run the simulations involved in ADS tests. Any support materials required at the distributed nodes would also account for an increase in test resources (supplies) for ADS tests.

2.1.2.5.2 Ability of ADS to Increase the Number of Test Events and Test Time

This section addresses the following JADS measures:

JADS Measure 1-2-3-9 Degree to which ADS increases the number of test events

JADS Measure 1-2-3-16 Degree to which ADS can overcome test area time/availability restrictions

Using ADS, testers can conduct more test events and test for longer periods of time than with traditional T&E because of the reduced cost and logistics required and the capability to maintain continuous and consecutive testing. All three JADS tests took advantage of these ADS testing capabilities to increase test events and test time.

For example, during Phases 2 and 4 of the ETE Test, the test team was able to test for more than 30 hours in a 1-week period. This amount of test time over a similar test period would be nearly impossible to match with a traditional test using real assets because of the cost and logistical restrictions. Similarly, the EW Test team was able to perform 271 runs during the two weeks of both the Phase 2 and Phase 3 tests. During the Phase 1 OAR test, the team was limited to 14.4 hours of testing over eleven months, obtaining only 136 runs. Without the ADS testing capability to support a continuous and consecutive test period, these results would not have been possible.

During the SIT LSP, two operational pilots replicated the actual engagement of a previously executed live missile shot. The ADS design allowed for the resetting of the engagement in just a few seconds. If this test had been executed by live aircraft it would have taken 5-10 minutes to return the aircraft on the range to the start position. In addition, fuel, weather, or flight-time limitations did not limit the aircraft or pilots in the SIT LSP. During the SIT LFP, the team obtained 14 valid runs in a 2-hour sortie that included refueling. Additionally, the ADS configuration allowed for the review of engagement results while the aircraft were returned to the start positions. This near real-time data review, which is not available during conventional range operations, allowed adjustments to be made for the next run. Conventional live testing would have allowed one run and analyzed the data after the aircraft had landed. ADS allowed the SIT to maximize the number of test runs and to meet test objectives.

2.1.2.5.3 Ability of ADS to Overcome a Lack of Personnel

This section addresses the following JADS Measures:

JADS Measure 1-2-3-13 Degree to which ADS can represent human interaction in simulation

JADS Measure 1-2-3-36 Degree to which ADS can increase personnel resources

A common shortfall of traditional T&E is the lack of manpower available to conduct test activities. This shortage in personnel resources can result in a reduced and sometimes insufficient testing capability. ADS has the potential to overcome a lack of personnel resources by replacing personnel with computer simulations which in turn interact with other virtual, live and constructive representations. For example, the ETE Test used the Tactical Army Fire Support Model (TAFSM) simulation as a replacement for the Army personnel that would have been needed in similar non-ADS tests. Another example is the simulated use of ground vehicles. Live testing requires an operator per vehicle as well as observer personnel. When all vehicles are synthetic only a simulation operator is required. Additionally, ADS allows you link personnel who would otherwise be unavailable. During the ETE test live GSM operators in garrison at Ft. Hood Texas who were unavailable for deployment as well as FDC and intelligence personnel were linked to the test environment.

The SIT and EW Test experienced the need for additional personnel to successfully execute their ADS-enhanced test. The ADS-based phases of the EW Test used from three to nine more people than similar non-ADS tests to accomplish the same goal. In this case, additional personnel were needed to monitor network performance and real-time visualization tools during the test execution, to observe simulation equipment, to gauge test operator performance, and to watch for system failures in the ADS architecture. The SIT had results similar to the EW Test in that personnel were needed to monitor system performance during the ADS portion of the test. The use of the TCAC during the LSP was an example of additional personnel requirements resulting from the use of ADS supported distributed testing. During the LSP, personnel were required to conduct, control, and monitor the test from Albuquerque. With ADS-enhanced testing, a central node where the test can be controlled is needed. This node must provide the ability to monitor the entire network during the test. In addition, all the nodes must provide personnel to interface with the central node. These personnel requirements, however, are not necessarily unlike the requirements for traditional testing. Personnel for test control and monitoring are required for traditional testing, as are people to coordinate at each test site. The requirement for additional ADS test control personnel is related to network instrumentation and monitoring requirements that are not required for some traditional tests. In the EW test, the requirement for observers at the manned threat locations was not an ADS requirement as well. JADS chose to place observers at each threat location to monitor operator performance and control for operator induced variability.

Overall, simulation of personnel actions is possible for testing various systems, but the requirement for monitoring personnel at each of the distributed sites may exceed the personnel

requirement using a nondistributed test approach. In field tests involving dispersed sites, the need for monitoring personnel is essentially the same.

2.1.2.5.4 Ability of ADS to Overcome Traditional T&E Restrictions

This section addresses the following JADS measures:

JADS Measure 1-2-3-2 Degree to which ADS allows for electronic combat

JADS Measure 1-2-3-3 Degree to which ADS overcomes performance restrictions

JADS Measure 1-2-3-10 Degree to which ADS can overcome ordinance/chaff/flare restrictions

JADS Measure 1-2-3-22 Degree to which ADS can provide for representative electromagnetic environments

JADS Measure 1-2-3-27 Degree to which ADS can overcome traditional testing constraints imposed because of security restrictions

JADS Measure 1-2-3-38 Degree to which ADS can overcome environmental impact restrictions

Traditional T&E is often adversely affected by restrictions imposed by performance, safety, environmental, and security factors. Unsafe conditions, restricted tactics, reduced maneuvering speeds and locations, the lack of test and communication assets, and electromagnetic and environmental restrictions are just some of the limitations that can negatively impact the robustness of a typical test.

ADS can be helpful in overcoming these shortfalls. For example the SIT LSP used the capability to investigate tactics using pilots in aircraft simulators linked to a simulated missile in a hardware in the loop facility. An ADS configuration such as this can allow pilots to examine portions of the envelope too dangerous to examine on the open range. While tactics development was not specifically the focus of this test, the SIT could have been expanded to test new and improved tactics normally too dangerous to implement in a nonsimulation-based test.

For the SIT, ADS offered the capability to perform multiple flyouts of the same missile engagement; a missile engagement that could not have been flown live because of safety restrictions. ADS provided the capability to perform more repeatable and robust testing before expending live missile assets. Additionally, ADS can overcome ordinance, chaff and flare restrictions. Testing with actual chaff and flares is restricted because of the potential of an errant live missile. A key feature in the SIT LSP Mission #2: Parametric Study Mission was the use of counter measures involving the ejection of flares. Baseline validation profile V2 involved variable flare dispense times based on the automatic transmission of a flare PDU from the WSIC. Although JADS did not specifically simulate the use of chaff in the SIT (or EW) test, the TSLA study describes how this can be done. The SIT LFP ADS architecture also demonstrated the

potential to use ECM techniques. ECM techniques could be used against the missile and fire control radar of the shooter aircraft in a SIT LFP test configuration overcoming the range restrictions of traditional live testing.

For the ETE Test, maneuvering speeds, usage of simulated hostile territory landscapes, and the addition of thousands of trackable entities resolved many problems of traditional T&E testing. Because of the resolution of these problems, the ETE Test was able to execute a corps-size test with up to 10,000 entities using tactics and movements that would have been restricted in a non-ADS based test. There is no environmental impact from virtual vehicles operating in a synthetic test environment. In terms of overcoming ordinance restrictions in the ETE test, ADS allowed the firing of a synthetic ATACMS at synthetic troops. This would be impossible to do in a traditional test.

For EW tests, non-ADS tests do not allow live missile flyouts against a SUT or target aircraft. Instead, missile models are used to allow OT&E measurements to be made on both SUT and threat performance. The JADS EW test was designed to test the ability of ADS to overcome traditional test and evaluation shortcomings related to the use of electronic combat. The results of the EW test demonstrate that ADS can overcome many of the T&E shortfalls associated with electronic combat testing. The EW test RF federate was designed to provide for a representative electromagnetic environment. Unfortunately JADS was unable to capture a representative environment from the OAR phase of testing, but conceptually this is possible. The EW test did, however, demonstrate the capability to use jamming techniques that the Federal Communications Commission (FCC) and the Federal Aviation Administration (FAA) would not allow on the open range. Although, the JADS EW Test was not specifically designed to address possible environmental issues or the use of dangerous maneuvers, future tests could accomplish this if HITL aircraft simulations were used. The EW Test used a scripted aircraft position to assess ADS effects, but a test could be designed that allowed pilot interactions with threat operators to determine a more realistic outcome for an OT&E test.

By providing large numbers of assets, depicting unsafe conditions in convoy movements and aircraft and missile engagements, and applying tactics normally restricted in typical T&E, the ADS testing technology increased test robustness for the three JADS tests. In all cases however, the elimination of T&E shortfalls was accomplished at the cost of the implementation of ADS, which can be higher than the cost of a non-ADS test. Concurrent with ADS implementation, complexity is added on many levels to test planning, test rehearsal, execution, and analysis. The test manager must be prepared to include additional time, money, and staffing to accommodate the growth in test complexity if ADS is used. Failure to prepare for the additional requirements needed to implement ADS will severely diminish the added benefits of ADS in overcoming the performance, environmental, and safety considerations inherent in traditional T&E.

2.1.2.5.5 Ability of ADS to Overcome the Inadequate Number of Systems for Interoperability Testing and Compatibility Evaluation

This section addresses the following JADS measures:

JADS Measure 1-2-3-7 Degree to which ADS overcomes the lack of systems for interoperability testing associated with traditional T&E

JADS Measure 1-2-3-12 Degree to which ADS can increase the number of systems for compatibility evaluation

Traditional tests are often unable to perform interoperability testing or system compatibility evaluations because of the limited number of systems available on site. ADS can give testers the capability to overcome these shortfalls. By linking multiple systems from distributed sites, ADS tests provide the opportunity to conduct interoperability testing and compatibility evaluations that would be difficult if not impossible for most traditional tests.

For the ETE Test, there were many interoperability and compatibility problems among the fielded real systems used. Up to the time that the ETE Test occurred, the target analysis cell (TAC) had never had the opportunity to accomplish interoperability testing or compatibility evaluations under tactical conditions in a doctrinally correct manner. During the ETE Test, several systems were able to operate together and function as intended during combat-like conditions. Specifically, the light ground station model (LGSM) was electronically linked to the All Source Analysis System (ASAS) workstations located within the TAC and provided a complete operational picture of an enemy corps rear area. In addition, the ASAS workstations were electronically linked to the Advanced Field Artillery Tactical Data System (AFATDS) terminal and electronically passed fire missions for prosecution by the ATACMS. Observer SMEs from III Corps intelligence community stated that this was the first time they had seen all these systems linked and operating as they should during a conflict.

The EW Test did not explicitly test interoperability issues because the scenario used was one SPJ against several threats. In the execution of the EW Test, an integrated air defense system (IADS) was simulated with the terminal threat hand-off (TTH) federate. This federate designated when each threat system would be activated against the target. This setup did not specifically test interoperability, but future tests could be changed to employ an actual IADS in the scenario. This would allow interoperability between air and ground forces in a combat simulation. It is also possible to add different aircraft to future EW tests such as the Joint Strike Fighter (JSF) or the F-22 to test interoperability among joint forces when multiple aircraft are engaging multiple threats.

The SIT identified potential uses of ADS to overcome T&E interoperability shortfalls in conventional air-to-air missile testing. Conventional missile testing has a limited number of live shots and systems because of cost considerations. This limits the robust testing of missiles and their associated support systems in a variety of engagement scenarios. Architecture similar to the SIT LFP architecture could be used to identify potential problems between the shooter's avionics and missile. In traditional T&E such a deficiency would not be identified until live

missiles were actually fired and lost. The solution to such a problem is easily implemented and valuable live testing could be saved if the problem was identified before live missiles were fired. An ADS architecture like the SIT LFP architecture could be used to identify interoperability problems by linking the aircraft, aircraft support systems, and missile in a more robust manner than a stand-alone lab or captive carry testing.

2.1.2.5.6 Ability of ADS to Facilitate the Use of Correct Techniques and Procedures

This section addresses the following JADS measures:

JADS Measure 1-2-3-24 Degree to which ADS can insure that correct techniques and procedures are used

JADS Measure 1-2-3-33 Degree to which ADS can provide for target control

JADS Measure 1-2-3-39 Degree to which ADS can facilitate the proper use of friend, foe, and neutral tactics

In certain tests, incorrect techniques and procedures may be used, often as a result of missing systems or components and/or restrictions placed upon the use of systems, components, techniques, and procedures. ADS allows for systems or components not physically located together to be linked during testing. This can enable a test to apply the correct techniques and procedures.

For example, prior to the use of ADS in the ETE Test, intelligence data from Joint STARS were usually supplied to the ASAS in the form of verbal or written reports. This was because without ADS there was no way to link Joint STARS to the test scenario and provide operationally significant radar reports. This procedure was doctrinally incorrect. The ground-based portion of Joint STARS, the LGSM, would actually have been electronically linked to the ASAS workstation to pass radar reports to the analysts working in the analysis and control element (ACE). The use of ADS in the ETE Test enabled the use of correct techniques and procedures for this combat scenario.

The SIT identified potential uses for ADS in improving the ability to use correct procedures during testing efforts. During conventional live shot testing of air-to-air missiles, the targets are unmanned drones. These drones are remotely operated and, in most cases, they are older aircraft with performance capabilities that do not represent current threats. The SIT LFP allowed for the use of current manned aircraft to perform the engagement scenarios. The use of manned aircraft enhanced the ability to use correct engagement maneuvers for both target and shooter. In addition, ADS may allow the use of countermeasures for the engagements. This use of correct techniques with ADS can improve the quality of testing available prior to actual live shots.

Unfortunately, the EW Test did not overcome any use of incorrect techniques seen in non-ADS tests. In fact, the operational staffing of one threat system was different between the OAR and AFEWES testing sites. This was due to conflicting intelligence data and the following implementation of operating the threat system. For the SUT, the most effective or battle worthy

ECM technique was not used against one threat to allow the threat system an opportunity to engage the target. In a combat situation, the most effective ECM technique would be used in the pod to ensure the highest effectiveness. Furthermore, the rules of engagement (ROE) used at each threat site were not doctrinally correct. The ROE were intended to reduce the variability effects of human operators on the MOP results, but this proved ineffective. For future EW tests, the difficulty will lie in deciding which system's performance will be assessed. To assess SUT performance, it may be necessary to regulate threat operator actions to improve consistency across runs. For the EW Test, it was very difficult to simultaneously address both developmental and operational test measures within the same test design. However, the principal interest of JADS was assessing the ability of the architecture to support EW testing as opposed to rigorous testing of the SUT.

ADS possesses the potential to link systems to operate in a doctrinally correct manner, but this added capability cannot be realized unless the test design fully incorporates and assesses the use of doctrinally correct techniques and procedures.

2.1.2.5.7 Ability of ADS to Represent Indirect Fire Tactics and Capabilities

This section addresses the following JADS measure:

JADS Measure 1-2-3-30 Degree to which ADS can represent indirect fire tactics and capabilities

ADS-enhanced tests can realistically portray indirect fire tactics and capabilities. This can be seen by examining the results of the ETE Test. The Phase 4 configuration for the ETE Test used the AFATDS command and control system, collocated with the TAC at Fort Hood, Texas, to request fire missions. TAFSM, located at Fort Sill, Oklahoma, processed the fire missions and executed them. When the ATACMS missile was fired in TAFSM, a fire protocol data unit (PDU) was broadcast from TAFSM. The Janus operator, located at the Army Training and Doctrine Command Analysis Center (TRAC), White Sands Missile Range (WSMR), New Mexico, was alerted that a mission was underway so that, if desired, the operator could examine the strike area and observe the effects. At the appropriate time, a detonate PDU was issued by TAFSM giving the calculated spill location for the missile's bomblets. Janus calculated the spill pattern for the bomblets and assessed the appropriate damage to the targets located within the spill's footprint. Once the damage was assessed, Janus broadcasted entity state protocol data units (ESPDU) reflecting the effects of the missile strike. This was a doctrinally correct representation of an ATACMS missile strike using approved missile flyout algorithms and approved weapons effects algorithms.

The EW Test system assessed only a minor instance of indirect fire tactics during the distributed test. In some of the excursion runs executed in Phases 2 and 3, the AFEWES site controller would call out simultaneous missile shots from each weapon system. The TTH federate also possessed the ability to encode messages for when specific threat sites should fire missiles at the target. This capability could be expanded to utilize an actual IADS to add more realism to the test scenario.

2.1.2.5.8 Ability of ADS to Overcome Shortfalls Relating to Threat/Friendly Systems

This section addresses the following JADS measures:

JADS Measure 1-2-3-6 Degree to which ADS overcomes traditional T&E shortfall of inadequate quantity and types of threat systems

JADS Measure 1-2-3-8 Degree to which ADS overcomes the use of improper threats used in traditional T&E

JADS Measure 1-2-3-11 Degree to which ADS overcomes the traditional T&E shortfall of inadequate quantity and types of targets/drones

JADS Measure 1-2-3-14 Degree to which ADS can provide adequate quantities and types of friendly systems

JADS Measure 1-2-3-21 Degree to which ADS can provide multidimensional threats

JADS Measure 1-2-3-39 Degree to which ADS can facilitate the proper use of friend, foe, and neutral tactics

The three JADS tests provided different results in the effort to overcome the T&E shortfalls of traditional testing in the area of adequate quantity and quality of targets, threats, and friendly systems. Overall, JADS did demonstrate the capability of ADS to overcome some of these shortfalls. However, the ability of ADS to overcome shortfalls in this area is not inherent to ADS implementation but is dependent on the test architecture and simulations used.

For the EW Test, the addition of ACETEF simulated threat systems to the HITL threat systems used at AFEWES provided for more quantity and flexibility than experienced with threat systems in traditional OAR or HITL testing. Specifically, during Phase 3 of the EW Test, additional threats were added in some runs to test the SUT response to multiple copies of the same threat radiating from different locations. This allowed the EW Test team to assess erratic behavior of the SUT when radiated by multiple signals of the same threat type. This was not possible during the OAR test because the desired additional signals were not available at the facility. This could have been done during the HITL phase if the JammEr Technique Simulator (JETS) system had been used in this fashion. During Phase 3, no erratic behavior was noted as a result of the additional threats, suggesting that many more threats could be added to the scenario. The addition of two additional threats imposed only a small impact to the test setup time. It merely required the implementation and usage of existing resources at ACETEF. No testing was performed in the EW Test to determine the ability to add friendly entities to the test scenario.

The ETE Test did allow for the assessment of additional threat and friendly systems in an ADS-enhanced testing environment. The Janus system provided the capability to have many more friendly and threat entities than ever seen in a Joint STARS test. In traditional testing, corps-level testing is not possible, but with the implementation of ADS-enhanced testing, the total entity population was expanded to nearly 10,000 entities. The time and resources required to

accomplish this expansion were considerable. Any similar ADS effort should be considered carefully when deviating from a traditional test setup. Furthermore, in the Phase 4 ETE test, combining real assets with virtual assets used in the test scenario also required considerable planning and cost. Phase 4 relied extensively on the use of virtual assets, primarily because of the cost and the limited availability or limitations of live test assets. These virtual assets interacted with other virtual, constructive and live assets. Future ADS-enhanced tests must remain flexible when trying to execute such tests with a live/virtual mix of threat and friendly systems.

2.1.2.5.9 Ability of ADS to Test Integrated Avionics

This section addresses the following JADS measure:

JADS Measure 1-2-3-40 Degree to which ADS can test integrated avionics

In traditional tests, the ability to test integrated avionics is often limited. Conventional test methods and emulation of threat systems with poor fidelity may be inadequate, resulting in inconclusive or inaccurate test results. ADS technology can overcome this T&E shortfall, as shown in the SIT, by providing an improved capability to test integrated avionics.

During the SIT, the launch aircraft avionics were linked to actual missile hardware using tactical hardware, software, and message protocols. The SIT LSP and LFP ADS configurations were found to be useful for discrepancy/deficiency resolution, especially when there were interface issues/problems between/among weapon systems (e.g., the aircraft radar, mission computer, stores management system, and the missile). This included troubleshooting problems that proved to be difficult to replicate particularly those that appeared in flight tests but were not readily duplicated in stand-alone laboratory testing.

The SIT ADS-enhanced test configurations permitted the HWIL missile to respond to actual pre- and post-launch weapon system inputs instead of relying on stand-alone "canned" inputs. This allowed the HWIL to be tested in a more operationally realistic environment than would have been possible for a traditional test.

2.1.2.5.10 Ability of ADS to Overcome Traditional T&E Shortfalls Associated with Modeling and Simulation (M&S) and Can Provide High-Fidelity Emulators and Simulators

This section addresses the following JADS measures:

JADS Measure 1-2-3-18 Degree to which ADS can provide for improved mod/sim used for testing

JADS Measure 1-2-3-20 Degree to which ADS can overcome mod/sim's inability to replicate events/entities

JADS Measure 1-2-3-23 Degree to which ADS can provide high fidelity emulators and simulators used as targets and/or threats

JADS Measure 1-2-3-26 Degree to which ADS can facilitate mod/sim data collection

JADS Measure 1-2-3-37 Degree to which ADS can overcome mod/sim inflexibility

ADS technology can provide vastly improved models and simulations for use in testing. An inability to represent desired systems in a test environment is a common problem in traditional testing. With ADS, the tester no longer has to have all M&S assets physically located in a single location to include these assets in testing. This saves the expense of purchasing models and simulations and the difficulty involved in manning the simulated systems.

For the ETE Test, if the Army desired to test any Army components used in the test, they could obtain radar reports from VSTARS without owning and manning (with Air Force personnel) their own VSTARS. In a test such as the ETE Test, ADS-enhanced testing technology can ease the work required by linking simulations located across the country.

ADS also allows testers to assemble, using models, simulations, emulators, and fielded systems, systems of systems that either have not yet been built or would not exist except in time of war. The ETE Test, for the first time, allowed an ATACMS missile to be fired at an enemy force based on operationally realistic intelligence collected by Joint STARS and processed by an element of ASAS. This is just one example of a fielded system of systems. This ETE Test scenario also included the battle damage assessment provided by Joint STARS observing the hulks left behind and the fleeing survivors. All these components were electronically linked and functioning as they would in actual combat. Using this distributed testing environment, it would be a simple task to add the next generation ATACMS or ASAS and find out how it would function as a component in this system of systems.

In addition, ADS technology is flexible enough to support a wide range of simulation fidelity requirements depending on the type of testing being accomplished. For example, if a system under test is conducting early developmental testing, the fidelity requirements may be significantly lower than a system approaching OT. The EW Test showed the possibilities of linking low-fidelity SUTs to high-fidelity threat simulators to track system performance through

the acquisition process. The EW Test environment also possessed the ability to test a high-fidelity SUT against low-fidelity threats, as seen in Phase 1 of the SIT.

Lastly, ADS can easily employ models and simulations that represent the threats of today and the threats of tomorrow. All models and simulations of threats, no matter what their fidelity, are data driven. The fidelity is determined by the accuracy and detail contained within the data and the fidelity of the algorithms that use the data to depict the threat. During the ETE Test, the threats used were those currently fielded within the Iraqi Army. They could just as easily have been low-observable threats from a future battlefield. Just change the data (radar cross section) and the radar reports change drastically to reflect a potential future battlefield. For the EW Test, simulation of real-world threat systems was a more difficult task. Threat system data used in the AFEWES simulation were based on collected intelligence data. As the collected data become more readily available, the equipment needed to create effective and realistic simulators is the next issue. Foreign material is scarcely available to create the highest fidelity of simulators. Furthermore, the operations tactics of foreign threat systems often change making it even more difficult to maintain currency for those threat systems.

Overall, ADS inherently adds the ability to link assets of varied fidelity, but the creation and maintenance of those high-fidelity models are not necessarily made easier by the implementation of a distributed testing environment.

2.1.2.5.11 Ability of ADS to Represent Joint/Combined Operations and Capabilities

This section addresses the following JADS measure:

JADS Measure 1-2-3-31 Degree to which ADS can represent joint/combined operations and capabilities

ADS-enhanced tests can realistically portray joint/combined operations. The Phase 4 ETE OT was a joint operation that employed a mix of Air Force and Army personnel located at different facilities successfully simulating a C4ISR system interacting with ground-based units. Given more of the necessary planning and resources needed, ADS could also represent combined operations between forces of two or more allies. The Janus simulation used is capable of portraying up to six different categories of forces. Since the scenario was set in Iraq, it would have been an easy task to include forces from Kuwait or other North Atlantic Treaty Organization (NATO) forces in the scenario, thereby creating a combined operation.

Neither the SIT nor the EW Test used joint or combined operations in their test scenarios. At best, both tests used multiservice test facilities in the execution of the test phases, but this did not represent combined operations used in some traditional tests.

2.1.2.5.12 Ability of ADS to Enhance the Analysis Process

This section addresses the following JADS measures:

JADS Measure 1-2-3-34 Degree to which ADS can provide for real-time analysis

JADS Measure 1-2-3-35 Degree to which ADS can overcome the incompatibility of collected data

This section examines the ability of ADS test participants to conduct real-time analysis during testing. Real-time analysis was conducted during all of the JADS tests. For the SIT, using a live shooter-target ADS architecture provided the JADS analysts with immediate feedback on each pass of a multiple pass mission. This allowed adjustments to be made to the remaining test matrix, if necessary, while the live shooter and target platforms were still on range. This "analyst-in-the-loop" feature of ADS testing would be especially useful in efficiently progressing through an ECM testing matrix which involves varying a number of ECM-related parameters. For the ETE Test, network monitoring tools and the Janus/logger data collection capabilities provided data to JADS analysts allowing for real-time analysis. These tools provided data on the network links, PDU rates, types of PDUs being passed, and the total number of PDUs logged at each node. Analysis of these data during test trials was important in ensuring that the test was functioning properly with all nodes passing the expected amount and type of data. Real-time analysis for the ETE Test was limited, however, by the inability to manipulate log files during testing without losing test data. The initial analysis of log files had to be delayed until immediately after each test trial.

During the EW Test, written data were collected on each active threat and analyzed immediately by operators in the TCAC. This provided feedback on how the federation systems were performing and the quality of the SUT data being generated. This real-time analysis required more personnel than would have been necessary during a non-ADS test but it also resulted in minimizing delays in acquiring in-depth knowledge about test performance.

The use of ADS requires an integrated, systems engineering approach to the test planning process to insure compatibility of data. During all three of the JADS tests data had to be transformed so that they could be manipulated and analyzed to address JADS measures. The JADS test teams documented the type and amount of data that had to be transformed and the methodology and tools used to transfer them. Also see section 2.2.1-2.2.2 for further discussion of JADS analysis results.

2.1.2.5.13 Ability of ADS to Enhance Instrumentation

This section addresses the following JADS measures:

JADS Measure 1-2-3-5 Degree to which ADS overcomes traditional T&E shortfall of inadequate instrumentation

JADS Measure 1-2-3-32 Degree to which ADS can provide for real-time instrumentation

In general, ADS tests do little to overcome instrumentation shortfalls of traditional tests. If instrumentation is inadequate or incapable of providing real-time data for a non-ADS test, development of an ADS test will not necessarily overcome these problems without additional effort. This is especially true for ADS tests that have specific data transfer requirements, which may not be fulfilled by existing instrumentation. Additionally, ADS tests applying a mix of live and virtual assets will normally require the same instrumentation for the live assets as would be required in traditional testing. ADS testing also generates instrumentation requirements that are specific to distributed architectures. The network itself must be extensively instrumented so that anomalies introduced by the network are distinguishable from anomalies associated with the SUT.

Of the three JADS tests, only the instrumentation for the EW Test showed a significant improvement over similar non-ADS tests. The most notable improvement of ADS over non-ADS instrumentation was in the data analysis and visualization instrumentation. For the EW Test ADS phases, the instrumentation allowed for much better insight into the MOP data points as each run was executed. The added insight from the resulting real-time analysis was beneficial in evaluating test performance. Also see section 2.2.1.1 for further discussion.

2.2 Concerns, Constraints, and Methodologies

The second JADS issue addresses the limitations in the application of ADS to T&E. JADS used three objectives to address Issue 2. Objective 2-1 addressed characteristics such as instrumentation, interface performance, bandwidth, latency and data transfer performance to determine if the current state of technology provides the necessary fidelity and is of the necessary maturity for T&E applications. Objective 2-2 relates to ADS support systems for T&E such as data management and analysis systems and configuration management. Objective 2-3 required that JADS develop new and assess current methodologies for the use of ADS in T&E.

Issue	Objective
Issue 2: What are the critical constraints, concerns and methodologies when using ADS for T&E?	Objective 2-1: Assess the critical constraints and concerns in ADS performance for T&E.
	Objective 2-2: Assess the critical constraints and concerns in ADS support systems for T&E.
	Objective 2-3: Develop and assess methodologies associated with ADS for T&E.

Section 2.2.1 below addresses the critical concerns and constraints relating to ADS performance for T&E applications. To assess ADS performance JADS looked at player instrumentation and interface performance, network and communications performance and the impact of reliability, availability and maintainability on T&E. Section 2.2.2 examines the critical constraints and concerns in ADS support systems for T&E. JADS assessed ADS support systems for T&E from the perspective of data management and analysis systems and configuration management. JADS Section 2.2.3 outlines useful procedures for implementing ADS for T&E.

2.2.1 Critical Constraints, Concerns, in ADS Performance for T&E

2.2.1.1 Player Instrumentation and Interface Performance

The three JADS tests utilized very different types of instrumentation in the execution of the various test phases. For the EW Test, instrumentation in the ADS portion was significantly improved over the non-ADS tests. This was mainly in the form of instrumentation for data analysis and visualization. The non-ADS tests all used threat site observers and a control room to view the overall scenario, but viewing MOP results was not possible until the ADS test phases. In these phases, the Automated Data Reduction Software (ADRS) and the analysis federate applications offered much better insight into the MOP data points as each run was executed. These were very valuable assets for test control. Similarly, during the OAR test phases, instrumentation was not available to collect the jamming-to-signal ratio (J/S) data desired from these test phases. The test design planned to modify the Radar Detection and Performance Analysis System (RDAPAS) to collect these data, but in the end, the system was not capable of

collecting the needed J/S data for any threat system. The existing instrumentation used in the non-ADS tests was quite informative and useful, especially during post-test analysis, but the added insight from the real-time analysis tools was more beneficial.

The ETE Test had several instrumentation issues, the biggest of which was the instrumentation of live assets for Phase 4. This instrumentation was a major undertaking for the ETE Test because of the scheduling difficulties and the cost involved. Contrarily, the instrumentation of the virtual entities for each test phase was exceedingly easy because the Janus system was designed to use DIS PDU formats. The combination of the live instrumented entities and virtual entities in the test environment was also a formidable obstacle in test execution, as the necessary information had to be stripped from PDUs before being sent to the VSTARS system on board the E-8C aircraft to minimize the amount of satellite communications (SATCOM) bandwidth used.

The SIT also experienced difficulties in the instrumentation of live assets to be used in a simulation environment. The latency encountered from the global positioning system (GPS) pods on the shooter and target aircraft severely limited the intended scenarios available for use. Because timely instrumentation of the aircraft positions linked to the missile simulator was troublesome, very few maneuvering flight scenarios could be used during test execution. In this case, the problem for SIT was not the ability to instrument but rather the ability to instrument and pass the required data to the appropriate destinations in a timely fashion.

Overall, ADS does little to overcome instrumentation shortfalls of the T&E community. If instrumentation is not available for a non-ADS test, developing an ADS-enhanced test will usually not overcome this problem. In addition, in cases such as SIT, available instrumentation may not be able to pass the required data to the destination in a timely fashion, further limiting the usefulness of an ADS-enhanced test. Instrumentation problems are not usually solved by placing the components in an ADS environment, but doing this may exacerbate any problems currently existing in this area.

2.2.1.2 Network and Communications Performance

One of the primary purposes of JADS testing was to determine if current network and high-speed data communications structures were capable of supporting testing and training in an ADS environment. Specifically, JADS assessed the network capability in three key areas: adequate bandwidth to transfer large quantities of data from one node to another; the ability to transfer these data from one entity or host to another with minimal delays (latency); and the ability to transfer the data completely and accurately (minimal data losses/corrupt data). The means used to test these network and communications systems capabilities and the performance results are discussed below.

Bandwidth

The three JADS tests used multiple methods to transfer data from one node to another. These included T-1, T-3 lines, and RF satellite capabilities. The use of each data transfer method and its bandwidth characteristics is discussed below.

The ETE and EW tests used T-1 lines to connect different nodes and transmit data. The T-1 lines have a normal bandwidth of 1.544 megabits per second (Mbps). A small portion of this bandwidth was partitioned off to provide a secure voice channel during both tests leaving a bandwidth of 1.344 Mbps to transmit data. SPECTRUM[®] monitored bandwidth based on what was left for data. Network link performance data from the T-1 line, including packet rate and percentage of bandwidth utilized, were collected and studied using the SPECTRUM network analysis tool. A polling rate of 15 seconds was used for the ETE Test and a polling rate of 30 seconds was used for the EW Test. Once all the data were gathered, the JADS analysts consolidated the data by network link. These data were then used to calculate daily packet rate and bandwidth values (maximum and average) for each link. The bandwidth values were provided by SPECTRUM as the percentage of bandwidth available on the T-1 line.

The ETE Test also used a SATCOM link to transfer stripped PDU data from the ground data terminal (GDT) to the air data terminal (ADT) on the E-8C. Because of the limited capacity of the SATCOM link, the PDUs were stripped from 1156 bytes to 192 bytes to minimize data losses that could have resulted from bandwidth restrictions. Because of the limited measurement capabilities on the E-8C aircraft, no bandwidth data could be collected for this link.

As was the case with the ETE and EW tests, the LSP phase of the SIT employed T-1 lines to connect nodes and transfer data. Each simulation node (Weapon System Support Facility [WSSF], Weapons System Integration Center [WSIC], Simulation Laboratory [SIMLAB]) was DIS compliant and encrypted. The network data exchange protocol was DIS Version 2.0.4, except for the stores management system (SMS) data exchange between the F/A-18 WSSF and the AIM-9 SIMLAB. ESPDUs were generated at each player's node and passed to all other nodes via T-1 lines for use as required at those nodes. A T-1 link between the nodes and the JADS TCAC allowed JADS personnel to monitor and control the simulated intercepts.

In the LFP, two live F-16 fighter aircraft flying over a range were linked to the AMRAAM AIM-120 HWIL simulation facility. GPS and telemetry data were downlinked from the aircraft and combined by the time-space-position information (TSPI) data processor (TDP) to produce optimal entity state solutions. The aircraft entity state data were transformed into DIS PDUs and transferred to the AMRAAM HWIL laboratory over a T-3 link. The shooter aircraft "fired" the AMRAAM in the MISILAB at the target and provided data link updates of the target position and velocity to the missile during its flyout. The AMRAAM seeker was mounted on a flight table and responded to RF sources in the Missile Simulation Laboratory (MISILAB) which simulated the seeker return from the target, the relative motions of the target and the missile, and ECM. A T-1 link between the Central Control Facility (CCF) and the JADS TCAC allowed JADS personnel to monitor the simulated intercepts.

Prior to the installation of the network, the SIT analysts estimated the expected PDU traffic from each site. Along with this expected PDU traffic, any additional network traffic was considered in determining the hardware requirements. After the initial installation, baseline testing was conducted by sending PDUs across the network. During the actual test, JADS analysts monitored the bandwidth usage with SPECTRUM software tools.

The average and peak packet rates and load values experienced for each of the three JADS tests are presented in the following tables. These tables refer only to active test time during which PDU loggers were recording data.

Table 6. ETE Test Bandwidth Usage

Phase	Node A	Node B	Load		Packet Rate	
			Average	Peak	Average	Peak
2	T	G	0.58%	20.0%	17.92/sec	120.0/sec
	G	H	1.07%	5.0%	33.74/sec	102.0/sec
3	T	G	.58%	20.0%	17.92/sec	120.0/sec
	G	H	1.07%	5.0%	33.74/sec	102.0/sec
4	T	G	.6%	*69%	15.1/sec	345.0/sec
	G	H	.3%	4%	15.5/sec	93.0/sec
Total	T	G	0.59%	20.0%	16.98/sec	120.0/sec
	G	H	.81%	5.0%	27.66/sec	102.0/sec

G = Northrop Grumman

H = Fort Hood

T = TCAC

*The peak bandwidth of 69% was due to non-test software development activities at the TCAC. These activities were halted once the effect on bandwidth was discovered.

Table 7. EW Test Bandwidth Usage

Phase	Node A	Node B	Load		Packet Rate	
			Average	Peak	Average	Peak
2	JADS	AFW	6.75%	27%	54.33/sec	198/sec
	JADS	ACE	2.96%	11%	28.68/sec	103/sec
	AFW	ACE	4.18%	19%	32.95/sec	138/sec
3	JADS	AFW	5.53%	65%	46.21/sec	315/sec
	JADS	ACE	2.73%	10%	26.74/sec	85/sec
	AFW	ACE	2.51%	21%	20.67/sec	151/sec
Total	JADS	AFW	6.14%	65%	50.27/sec	315/sec
	JADS	ACE	2.85%	11%	27.71/sec	103/sec
	AFW	ACE	3.35%	21%	26.81/sec	151/sec

AFW = AFEWES

ACE = ACETEF

*The peak packet rate and utilized bandwidth values were all captured on the fourth day of test execution while excursions were being run with four active threats.

Table 8. SIT Bandwidth Usage

Phase	Network	Available Bandwidth (Mbps)	Max Load	Max Packet Rate
LSP	Point Mugu-China Lake (T-1)	2.048	4 %	Not Measured
	WSSF-SIMLAB (LAN)	1.536	2%	Not Measured
LFP	CCF-MISILAB	44.736	<1%	201/sec
	CCF-TCAC	1.457	<3%	49/sec

LAN = local area network

Conclusion

T-1 lines used by JADS for all three tests provided more than adequate bandwidth to conduct ADS-enhanced tests. None of the tests were delayed or negatively impacted because of bandwidth constraints. The average load for all the tests was typically less than 10 percent. The peak load experienced by any of the tests was 69 percent and 65 percent of the available bandwidth during the ETE and EW tests, respectively. The ETE Test peak load was a result of non-test related activities and was resolved before the completion of Phase 4. The EW Test peak load was measured during Phase 3; this peak occurred while four threat systems were active simultaneously during excursion runs. Neither peak load had a negative impact on the test. Likewise, the bandwidth constraints of the SATCOM link for the ETE Test did not have a negative impact. Stripping the PDUs to include only the essential bytes relieved the potential problems that could have resulted from the limited SATCOM link bandwidth. For the SIT, bandwidth problems were not experienced during either the LSP or LFP. The bandwidth usage was well within expected levels.

Latency

All the electronic data (PDUs, electronic messages) transmitted via T-1 lines or SATCOM links were time stamped and recorded at the transmitting and receiving node using loggers (developed by JADS analysts and contract agencies). The loggers specifically recorded the time and order that the PDUs/electronic messages were transmitted and received at each node. The data were later retrieved and correlated by JADS analysts to determine the latency (transmission time from node to node). These calculations were accomplished using UNIX™-based software tools created by JADS programmers. The results are as follows.

Table 9. ETE Test Latency Data

Phase	Node A	Node B	Latency (seconds)		
			Minimum	Mean	Maximum
2	W	T	0.016	0.039	0.145
	T	G	0.050	0.057	1.090
	S	W	0.030	0.035	0.396
3	W	T	.020	.047	.172
	T	G	-1.07*	-.42*	.152
	S	W	.036	.038	.375
4	W	T	.017	.046	.178
	T	G	.039	.058	.291
	S	W	.035	.038	.399
	Ground NIU	Air NIU	1.58	12.56	85.57
Total	W	T	0.016	0.044	0.178
	T	G	0.039	0.058	1.090
	S	W	0.030	0.037	0.399
	Ground NIU	Air NIU	1.58	12.56	85.57

G = Northrop Grumman
T = TCAC

NIU = network interface unit
W = WSMR

S = Fort Sill

*During Phase 3, logger clocks could not be synchronized at the Grumman node because of a problem with the time synchronization program. This resulted in negative latencies (not included in the calculations for the total column). This time synchronization problem was resolved during Phase 3.

For both ADS phases of the EW Test, node-to-node latency values across relevant network links were evaluated for six complex data message types. The six types were selected based on their ability to provide insight into the impact of latent traffic on SUT data validity.

Table 10. EW Test Phase 2 Latency Data (in milliseconds)

DATA ELEMENT	TYPE	JADS-AFEWES	JADS-ACETEF	AFEWES-ACETEF
LiveEntityState (A/C TSPI)	UDP	Avg: 43.9 Max: 859	Avg: 41.2 Max: 861	N/A
Threat Performance (Threat Track Data)	UDP	Avg: 45.9 Max: 860	Avg: 42.6 Max: 861	N/A
Threat Performance (T/E, J/S, Target Location)	UDP	Avg: 32.1 Max: 7975	N/A	Avg: 35.7 Max: 8540
SUT_Jammer_Tech (DSM RF Emissions)	TCP	N/A	Avg: 130 Max: 13951	Avg: 104.3 Max: 9680
SUT_Receiver_Track (Verify Environment)	TCP	N/A	Avg: 112.7 Max: 13982	N/A
Source_Mode Change (Threat RF Emission)	TCP	Avg: 101 Max: 9556	Avg: 66 Max: 8022	Avg: 61 Max: 7701

A/C = aircraft

T/E = tracking error

TCP = transmission control protocol

UDP = user datagram protocol

Table 11. EW Test Phase 3 Latency Data (in milliseconds)

DATA ELEMENT	TYPE	JADS-AFEWES	JADS-ACETEF	AFEWES-ACETEF
LiveEntityState (A/C TSPI)	UDP	Avg: 45.7 Max: 1150	Avg: 44.4 Max: 472	N/A
Threat Performance (Threat Track Data)	UDP	Avg: 52.7 Max: 1151	Avg: 52.3 Max: 516	N/A
Threat Performance (T/E, J/S, Target Location)	UDP	Avg: 30.0 Max: 515	N/A	Avg: 41.2 Max: 511
SUT_Jammer_Tech (DSM RF Emissions)	TCP	N/A	Avg: 75.3 Max: 312	Avg: 67.3 Max: 296
SUT_Receiver_Track (Verify Environment)	TCP	N/A	Avg: 77.0 Max: 267	N/A
Source_Mode Change (Threat RF Emission)	TCP	Avg: 55.7 Max: 372	Avg: 71.9 Max: 1548	Avg: 45.5 Max: 501

A/C = aircraft

T/E = tracking error

TCP = transmission control protocol

UDP = user datagram protocol

For the SIT, the latencies of all PDU traffic were monitored and recorded by JADS loggers. Table 12 shows the no de-to-node latency for the LSP. Table 13 shows the node-to-node latency for the LFP. The latencies were measured across T-1 or dedicated networks for LSP and T-1 or T-3 for the LFP.

Table 12. SIT LSP Latency Data

Phase	Node A	Node B	Latency (in milliseconds)	
			Mean	Std Dev
LSP	WSIC	SIMLAB	17.2	8.3
	SIMLAB	WSIC	22.3	18.3
	WSSF	WSIC	19.7	15.3
	WSIC	WSSF	19.2	8.1

Table 13. SIT LFP Latency Data

Phase	Node A	Node B	Latency (in milliseconds)	
			Mean	Std Dev
LFP	CCF	MISILAB	1.2	0.9
	MISILAB	CCF	8.2	4.2
	CCF	TCAC	28.6	5.0

Conclusion

The tables show that the test networks were very effective in maintaining stable latencies during the JADS tests. The only high latency issues for the ETE Test were associated with the SATCOM link. These high latencies were the result of the numerous buffers required on the E-8C to process the test data and were beyond the control of JADS personnel.

For the EW Test, seven percent and four percent of the runs for Phases 2 and 3, respectively, experienced high latencies. These anomalies were carefully researched to determine the impact of these latencies. Following this research, JADS analysts determined that the high latencies had almost no impact on the large majority of the runs, with only one run from Phase 2 excluded from the valid SUT data set and no Phase 3 runs excluded.

The latencies observed over the network for the SIT were as predicted by baseline testing of the network after the initial installation. The biggest contributor to latency was not the length of the network but rather how many interfaces the network traffic was passing through. The network latencies for both phases of the SIT were minor compared to the latencies observed when the individual simulators received and processed the PDUs from the network.

In general, the impact of high latencies on ADS-enhanced tests is dependent upon the type of test executed. Tests such as the ETE Test can sustain high latencies (even latencies as high as those experienced over the SATCOM link) and have no negative impact on test execution because of the inherent delays involved in human-in-the-loop systems. However, in the SIT and EW Test, high latencies could have caused serious problems and result in unusable trials. Test directors must consider these latency issues during test planning and determine the level of latency acceptable for their test.

Data Transfer Performance

The performance of the network and communications systems in transferring data was measured and analyzed for all the JADS tests. Specifically, the ability of these systems to transfer data completely and accurately with a minimal loss or corruption of data was the focus. This measurement and analysis was accomplished through the use of the log files created by the JADS loggers and the analysis tools created by the JADS program analysts. The results of the data transfer performance for the three tests are displayed in the following tables.

For the ETE Test, the effectiveness of the network and SATCOM link at passing data was evaluated through manipulation and comparison of PDU log files from each test location. This analysis was only possible because of the software tools created by the JADS program analysts. Log files containing more than 100,000 PDUs could be examined in minutes, a task that would have taken days without the software tools.

Table 14 shows the summary PDU data for each ETE Test phase by node including the SATCOM data from the live flight trials. No PDU loss rate, for any phase or the ETE Test as a whole, exceeded three percent of the PDUs sent. In addition, no corrupt (duplicate or out of order) PDUs were received. This shows the effectiveness of the network and SATCOM link at passing PDUs between ETE Test nodes.

For the EW Test, the effectiveness of data transfer across network links was measured and analyzed in terms of six complex data message types. The six types were selected based on their ability to provide insight into the impact of lost traffic on SUT data validity. In other words, these were the message types that if lost should have had the most noticeable effect on SUT behavior and SUT performance measure data.

Table 14. ETE Test PDU Data

Phase	Node A	Node B	PDU's Sent	PDU's Received	PDU's Lost/ Percent Lost	Corrupt PDU's
2	W	T	382,254	382,159	95 .025%	0
	T	G	382,159	381,959	200 .052%	0
	S	W	13,745	13,744	1 .007%	0
3	W	T	226,440	220,210	6,230 2.75%	0
	T	G	220,210	219,159	1,051 0.477%	0
	S	W	5,073	4,986	87 1.71%	0
4	W	T	953,456	947,442	6,014 0.63%	0
	T	G	947,442	944,002	3,440 0.36%	0
	S	W	30,089	30,077	12 0.04%	0
	NIU	E-8C	359,144	349,297	9,847 2.74%	0
Total	W	T	1,562,150	1,549,811	12,339 0.79%	0
	T	G	1,549,811	1,545,120	4,691 0.30	0
	S	W	48,907	48,807	100 0.20%	0
	NIU	E-8C	359,144	349,297	9,847 2.74%	0

E-8C = aircraft
S = Fort Sill

G = Northrop Grumman
T = TCAC

NIU = ground network interface unit at Grumman
W = WSMR

Table 15. EW Test Phase 2 Lost Data Traffic Messages by Link

DATA ELEMENT	TYPE	JADS-AFEWES	JADS-ACETEF	AFEWES-ACETEF
LiveEntityState (A/C TSPI)	UDP	Avg Lost: 6.9 Avg Sent: 4000 Percent Lost: < 1 Max: 503	Avg Lost: 18.6 Avg Sent: 4000 Percent Lost: < 1 Max: 1266	N/A
Threat Performance (Threat Track Data)	UDP	Avg Lost: 6.3 Avg Sent: 4000 Percent Lost: < 1 Max: 504	Avg Lost: 18.1 Avg Sent: 4000 Percent Lost: < 1 Max: 1266	N/A
Threat Performance (T/E, J/S, Target Location)	UDP	Avg Lost: 4.2 Avg Sent: 4000 Percent Lost: < 1 Max: 182	N/A	Avg Lost: 14.8 Avg Sent: 4000 Percent Lost: < 1 Max: 2222
SUT_Jammer_Tech (DSM RF Emissions)	TCP	N/A	Avg Lost: 0 Avg Sent: 9 Percent Lost: 0 Max: 0	Avg Lost: 0 Avg Sent: 9 Percent Lost: 0 Max: 0
SUT_Receiver_Track (Verify Environment)	TCP	N/A	Avg Lost: 0 Avg Sent: 96 Percent Lost: 0 Max: 0	N/A
Source_Mode Change (Threat RF Emission)	TCP	Avg Lost: 0 Avg Sent: 50 -90 Percent Lost: 0 Max: 0	N/A	Avg Lost: 0 Avg Sent: 50 - 90 Percent Lost: 0 Max: 0

A/C = aircraft

T/E = tracking error

TCP = transmission control protocol

UDP = user datagram protocol

Table 16. EW Test Phase 3 Lost Data Traffic Messages by Link

DATA ELEMENT	TYP E	JADS-AFEWES	JADS-ACETEF	AFEWES- ACETEF
LiveEntityState (A/C TSPI)	UDP	Avg Lost: .08 Avg Sent: 3900 Percent Lost: < 1 Max: 17	Avg Lost: 0 Avg Sent: 3900 Percent Lost: 0 Max: 0	N/A
Threat Performance (Threat Track Data)	UDP	Avg Lost: .08 Avg Sent: 3800 Percent Lost: < 1 Max: 17	Avg Lost: 0 Avg Sent: 3800 Percent Lost: 0 Max: 0	N/A
Threat Performance (T/E, J/S, Target Location)	UDP	Avg Lost: .2 Avg Sent: 3900 Percent Lost: < 1 Max: 36	N/A	Avg Lost: .002 Avg Sent: 3900 Percent Lost: < 1 Max: 1
SUT_Jammer_Tech (DSM RF Emissions)	TCP	N/A	Avg Lost: .006 Avg Sent: 10 Percent Lost: <1 Max: 1	Avg Lost: .006 Avg Sent: 10 Percent Lost: <1 Max: 1
SUT_Receiver_Track (Verify Environment)	TCP	N/A	Avg Lost: 0 Avg Sent: 116 Percent Lost: 0 Max: 0	N/A
Source_Mode Change (Threat RF Emission)	TCP	Avg Lost: 0 Avg Sent: 29 Percent Lost: 0 Max: 0	N/A	Avg Lost: 0 Avg Sent: 29 Percent Lost: 0 Max: 0

A/C = aircraft

T/E = tracking error

TCP = transmission control protocol

UDP = user datagram protocol

The network was very reliable in transferring data during the EW Test. No transmission control protocol (TCP) (reliable) data traffic losses were detected during Phase 2 and only one unique TCP reliable data traffic loss was found during Phase 3 (JADS analysts attribute responsibility for the lost TCP message to the runtime infrastructure (RTI) itself, but the specific cause could not be pinpointed). In addition, less than one percent of all user datagram protocol (UDP) (best effort) data traffic was lost in Phases 2 and 3. Only one run was excluded from the SUT valid data set in Phase 2, with no Phase 3 runs excluded.

During the SIT, PDU loggers were used to measure any missing, out-of-order, or corrupted PDUs. There were no instances of these problems for either the LFP or the LSP. The only noted problems were repeated shooter or missile PDUs during the LSP. These repeating PDUs were generated by the network interface units (NIUs) for unknown reasons. The repeaters caused some problems with dead reckoning of entity locations for display purposes. However, no target PDUs repeated, so no problems were experienced within the simulations and execution of the engagements.

Conclusion

Overall, the data transfer performance of the networks for the three JADS tests was excellent. The problems experienced were minor and did not negatively impact the success of the tests.

In addition, any concerns about the impact of the relationships among data transfer performance, bandwidth, and latency were dismissed because of the results reported for the three tests. Neither the peak bandwidth nor latency appeared to have any impact on the ability of the network to pass data reliably and accurately in an ADS-enhanced test environment. However, for distributed tests requiring a greater amount of data processing in a shorter test period, it is possible that the relationships of these network characteristics could become a concern.

2.2.1.3 Impact of Reliability, Availability, and Maintainability on T&E

The ability of ADS systems to be up and operating at scheduled test initialization and to remain operational throughout the test period is fundamental to the success of a distributed test. Distributed testing systems experiencing low levels of reliability, maintainability, and availability (RM&A) can cause test trials to be delayed, rescheduled, repeated, or canceled completely. For the three JADS tests, execution logs were maintained at each node to document the performance of the ADS systems involved and the overall status of the test trials. Following each test phase, system malfunctions and failures were examined in each area in terms of lost test time and loss of usable test trial data. This analysis provided insight which, in several cases, enabled system improvements to be made prior to the next phase of testing.

The following paragraphs and tables summarize the impacts of ADS system RM&A behavior across the three JADS tests in terms of test time and trial losses. First, ADS system hardware and software problems are presented exclusive of the network, personnel, and procedural problems that impacted testing. Detailed discussion of the problems in those areas follows.

ADS System Hardware and Software

Table 17. Test Trials Canceled/Aborted Because of ADS System Failures

Test	Phase	Total # of Trials	# of Trials Lost Because of ADS System Failures	% of Trials Lost Because of ADS System Failures
ETE	2	5	0	0 %
	3	7	3	43 %
	4	9	1	11 %
EW	2	363	83	23 %
	3	270	21	8 %
SIT	LSP	214	30	14%
	LFP	37	0	0%

As can be seen in Table 17, the ETE Test experienced the cancellation of four trials because of ADS system failures during Phases 3 and 4. Of the four trials lost, two were due to problems with VSTARS and two were due to the surveillance control data link (SCDL) at Northrop Grumman. In addition to these failures, 15 minor ADS system failures were experienced during Phases 2 through 4. These failures did not involve critical systems and did not result in a break in the ETE Test loop, thus avoiding any delays or cancellation of the trials.

Unlike each ETE Test trial, which filled an entire day's testing, an individual EW Test or SIT trial required only minutes to complete. Thus, when an EW Test or SIT trial had to be aborted because of a system malfunction or failure, the particular scenario being run was usually repeated immediately. This strategy for accomplishing runs allowed test controllers to monitor the overall test progress and the amount of usable data that had been collected.

Because of the nature of the EW Test and the short duration of each individual trial, looking at the number of lost test trials does not provide a complete picture of test federation RM&A performance. Each aborted trial resulted in lost data but not in a significant amount of lost test time. Table 17 provides additional insight into test federation RM&A by capturing time during which no active test trials were even attempted. This is time during which equipment was being troubleshoot and maintained or during which discussion about malfunctioning hardware and software delayed the restart of active trials. Operators were typically released on break for a short time if the ADS system problem was deemed severe enough to require more than ten minutes of maintenance activity. As the table shows, both phases resulted in close to the same number of hours being lost over nine test days. The main contributors to lost test time in Phase 2 were the hardware and software systems implemented to enable distribution, whereas the major problems experienced in Phase 3 were with existing test facility systems--problems which took some time to diagnose and fix.

EW Test Phase 2 RM&A analysis showed that, aside from the great deal of test time lost because of existing equipment malfunctions at one of the test facilities, the majority of lost test trials were

caused by federation and visualization tool software crashes. Based on this information, numerous problems were identified and fixed through software upgrades prior to Phase 3. These fixes were responsible for the significant drop (from 23 percent to only 8 percent) in the number of trials lost to these problems, as shown in Table 18. Thus, far fewer total runs were required in Phase 3 to obtain a satisfactory amount of usable SUT data.

Table 18. Time Lost Because of ADS System Failures

Test	Phase	Total Test Time	Total Time Lost Because of ADS System Failures	% of Time Lost Because of ADS System Failures
ETE	2	35 hrs, 27 mins	0 mins	0 %
	3	35 hrs, 13 mins	21 hrs	60 %
	4	57 hrs, 9 mins	8 hrs	14 %
EW	2	57 hrs, 12 mins	7 hrs, 18 mins	13 %
	3	48 hrs, 48 mins	10 hrs	21 %
SIT	LSP	19 hrs, 42 mins	2 hrs, 52 mins	15%
	LFP	3 hrs, 39 mins	0 mins	0%

The ETE Test time data in Table 18 were calculated with the assumption that trials canceled because of ADS system failures resulted in a loss of 7 hours of test time. This figure was used because each ETE Test vignette was designed to support 7 hours of testing with more or less time possible. ADS system failures that did not result in a cancellation of the trial (i.e., failures that did not result in a breakdown of the ETE Test loop) were not included. The table shows that 29 hours of test time, the equivalent of more than 4 days of testing, were lost because of ADS system failures, with the large majority of this time lost because of problems with the VSTARS software at Northrop Grumman.

Table 18 shows the lost time for both the SIT LSP and LFP. The LSP was the only phase that experienced lost test time because of ADS system failures. The 15 percent lost time figure for LSP was nearly evenly split between hardware and software failures. Most of the software failures required only minutes while simulation or network interfaces were reset. The three hardware failures included a missile hardware failure for approximately one hour and two failures involving cooling or power supplied to a node. During the LFP there were three hardware failures, none of which resulted in lost test time.

Personnel and Procedures

For all the JADS tests, detailed problem logs were kept at each of the sites to provide insight into the impacts of different types of ADS system RM&A problems. JADS personnel used these logs to document the behavior of existing facility hardware and software, hardware and software implemented to enable distribution, communications equipment, and the distributed network architecture. In addition, EW Test personnel used these problem logs to document personnel and procedural problems encountered during testing. Interestingly, for both Phases 2 and 3 of the EW Test, personnel and procedural problems accounted for the second largest number of delays and test trials lost, next to the combined ADS system hardware and software problems.

Table 19 shows the impact, in terms of lost test trials, of personnel and procedure problems experienced during the EW Test.

Table 19. EW Test Trials Canceled/Aborted Because of Personnel and Procedural Problems

EW Test Phase	Total # Of Trials	Total # of Aborted Trials	# of Trials Lost Because of Personnel and Procedure Problems	% of Trials Lost Because of Personnel and Procedure Problems
2	363	95	10	3 %
3	270	32	10	4 %

Phase 2 personnel and procedural difficulties included missing script files, incorrect script input, miscommunication among test controllers and test station operators, operator tardiness, and operator slowness or unfamiliarity with procedures. As a result of these problems, several procedures and checklists were made stricter for Phase 3. Following these changes, difficulty with personnel and procedures during Phase 3 execution consisted almost entirely of operator error based on miscommunication or simple lack of concentration.

Neither the ETE Test nor the SIT was affected as much by personnel and procedural issues as the EW Test. The ETE Test trials lasted an average of 7 hours. If personnel or procedural problems occurred, these problems could be resolved without any impact to the trials. For this reason, any personnel or procedural problems were minor and were not analyzed. For the SIT, very few personnel had to interact during the trial runs eliminating the potential for nearly any type of personnel failure. The most critical interaction was between the two pilots performing the desired flight engagements. In addition, the SIT had more extensive rehearsal time to refine procedures and train operators, resulting in the reduction of potential procedural failures. As was the case for the ETE Test, personnel and procedural failures were not a major issue for the SIT, and data on these failures were not analyzed.

Network RM&A

The same logs and analysis procedures used to study ADS hardware and software RM&A were also applied to network evaluation for each of the three JADS tests. Again, data collectors annotated all problems encountered, as well as their causes, and test controllers documented the overall status of the network and test trials. In addition, commercial and in-house network monitoring tools (e.g., SPECTRUM, NETVisualizer™, JADS Link-Availability Monitor) were used to monitor the status of all network equipment and links among nodes. Any problems detected by these monitoring tools were brought to the test controller's attention via on-screen lights or sounds, as well as stored to databases for further detailed analysis. The results of JADS network equipment self-diagnostics were documented via line printers in terms of a brief explanation of the problem, the time, and the link(s) involved.

The following paragraphs and tables detail the results of network reliability for each of the three tests and the impacts to testing of that reliability.

Table 20. ETE Test Cancellations/Postponements Because of Network Outages

Phase	Affected Trials	Comments
2	2	T-1 outage due to contractor/hurricane
3	N/A	No network cancellations/postponements
4	N/A	No network cancellations/postponements

Table 20 shows each ETE Test canceled/postponed trial. Overall, the ETE Test network performed with high reliability. No trials were canceled or not used because of network problems. However, two Phase 2 trials were postponed when the agency contracted to provide network service inadvertently terminated use of the T-1 line at the Northrop Grumman node. The coincidence of a hurricane hitting the Florida and Gulf coasts during the same time period delayed the reactivation of this link. As a result, the test was extended two days after the scheduled test period.

Table 21. ETE Test Network Downtime

ETE Test Phase	Time Scheduled for Testing	Time Network Unavailable for Testing	% of Time Network Unavailable
2	35 hrs, 27 mins	8 mins	0.38%
3	14 hrs, 13 mins	11 mins	1.29%
4	50 hrs, 9 mins	39 mins	1.30%
Total	99 hrs, 49 mins	58 mins	0.97%

The ETE Test network downtime experienced during test trials, by phase and for the test as a whole, can be seen in Table 21. Aside from the postponed trials caused by the contract agency error, the network was unavailable for less than one hour of the ETE Test over the course of all three phases. The majority of this downtime was due to network routers at the distributed nodes failing momentarily. This suggests a very high level of network reliability.

Table 22. EW Test Network Downtime

EW Test Phase	Time Scheduled for Testing	Time Network Unavailable for Testing	% of Time Network Unavailable
2	57 hrs, 12 mins	17 mins	< 0.50%
3	48 hrs, 48 mins	1 mins	< .03%
Total	106 hrs	18 mins	< .28%

Table 22 shows the EW Test network downtime. Network problems encountered during the EW Test Phase 2 were limited, resulting in just over 17 minutes of lost test time and two aborted runs. Specific problems included a bad Integrated Digital Network Exchange (IDNX™) voice card at ACETEF, ACETEF router problems, and a link between ACETEF and AFEWES going down momentarily. The bad voice card resulted in two additional trials being run using non-secure voice communication. During Phase 3, network problems caused just one trial to be aborted. The JADS-AFEWES link and a minor crypto problem were the cause of this brief network downtime. The impact of this downtime was insignificant with a minimal loss of TSPI data at AFEWES and two-way losses of best-effort (UDP) data and a delay of reliable (TCP) traffic over one network link.

Table 23. SIT Network Downtime

SIT Phase	Time Scheduled for Testing	Time Network Unavailable for Testing	% of Time Network Unavailable
LSP	19 hrs, 42 mins	0 mins	0 %
LFP	3 hrs, 39 mins	0 mins	0 %
Total	23 hrs, 21 mins	0 mins	0 %

Table 23 shows that there were no network outages during either phase of the SIT. The average length of a daily test using the network was approximately five hours. Since there were no outages, there was no impact on the test because of network reliability.

2.2.2 Critical Constraints and Concerns in ADS Support Systems for T&E

2.2.2.1 Data Management and Analysis Systems

The three JADS tests showed that data collection, retrieval, and storage methodologies do not need to be more complex for distributed tests than for traditional non-ADS tests, and that, in some ways, ADS data management techniques can be simpler and more efficient than their traditional counterparts. JADS tests showed that both automated and handwritten data were easily collected and retrieved from distributed sites with electronic data transfer via file transfer protocol (FTP) speeding the process and allowing for more timely and thorough initial review.

The test teams used many similar data collection and retrieval methods with data handling dependent primarily on the particular format of the data generated, either electronic (produced and collected by automated tools and systems) or operational (usually in the form of handwritten or typed log forms). For the ETE Test and the SIT, automated data were collected through the use of tools such as the JADS logger, which collected PDU log files, and a SPECTRUM logger, which monitored network performance. These data were retrieved at the TCAC following each test day using FTP. Operational data were collected using log sheets at each test node. JADS personnel transported these data to Albuquerque following each test phase.

Data handling for the EW Test differed little, although data from a few additional automated data collection tools (e.g., ETHERPEEK™ data packet sniffers implemented across the network to characterize data transfer), as well as distributed simulation (e.g., AFEWES threat system) performance data, added to the complexity and amount of data. In addition, the JADS EW Test log files, generated at each site and collected daily, handled HLA-compliant federation data versus the ETE Test's DIS PDUs. The test teams encountered no significant problems during the collection and retrieval efforts for either the operational or automated data.

Similarly, no major problems were experienced in data storage. All log files from each test node were stored on hard drives and backed up to tape. The only adjustment required for data storage for the ETE Test was the installation of 4-gigabyte (GB) hard drives because of the large size of the log files. The EW Test team stressed the importance of having good documentation for storage of electronic data including clear and detailed directory structures. Handwritten log sheets and operator questionnaires from each node were maintained in test controller or analyst notebooks for easy access. The successful implementation of these storage methods, along with the collection and retrieval methods employed, show the level of simplicity which can be maintained for data management of ADS-enhanced tests.

The EW Test, with its ADS and non-ADS test phases, enabled analysts to make comparisons between the data management techniques used. During the OAR test (non-ADS), personnel at the threat sites and in the control center performed written data collection. Digital range data were delivered post-mission to JADS where they were catalogued, analyzed, and stored. This data collection method did not allow for a great deal of immediate feedback on the SUT and threat performance. On the other hand, the delay between missions did allow for fixes in data collection processes, data collection equipment, and the SUT itself. For Phase 2 and 3 (ADS), written data were collected by personnel at each active threat, by the controller at each site, and

in the TCAC by operators performing real-time analysis. This data collection method allowed for more immediate feedback as to how all federation systems were performing and provided insight into the quality of the SUT data being generated, allowing system flaws to be fixed almost immediately. While the ADS-enhanced tests required more personnel during test execution to perform data collection and retrieval, the result was less delay in acquiring in-depth knowledge about test performance.

Another difference in data management between ADS testing and non-ADS testing for the EW Test was the technique by which electronic data were transferred. The OAR test allowed for a single compact disk to be delivered to JADS containing all the necessary data, whereas the ADS tests used daily FTP transfers to accomplish most of the data delivery. The OAR approach packaged the data nicely and made them easier to manage but also required a long time to discover and replace any corrupted or missing data. The distributed tests allowed for quicker responses to data being lost or not transferred but also required much more management and controlled placement of the information.

Lastly, there were differences in the actual amount and type of data created by the two types of tests. ADS-enhanced tests produce more data than non-ADS tests. In addition to the requirement to collect SUT, threat, and operator performance data, network data must also be collected. Overall, ADS-enhanced testing added more flexibility for data management and quicker insight into the quality of collected test data, but it did require more organization and documentation to make data handling techniques effective.

2.2.2.2 Configuration Management

Configuration management for the JADS tests proved to be a difficult task. ADS-enhanced testing makes configuration management more complex than in single-site test efforts because of the different organizations involved. The JADS test managers did not have complete control over the software or systems at the distributed test nodes, in part due to limited budget and low priority. Existing configuration management procedures at the different facilities were used. This alleviated some test problems, but since each facility possessed individual configuration management processes, a single configuration management standard could not be created. This is a potential weakness for ADS-enhanced tests in general but not a disastrous one. This lack of centralized control was overcome by the JADS tests in a variety of ways.

JADS test managers maintained close contact with personnel from contracted agencies and conducted frequent meetings with test participants. This gave the test manager the ability to track configuration management progress and problems and provided a forum for system experts to resolve issues. For ADS-enhanced tests in general, this increased level of management is vital to ensure effective configuration management with a focus on top-down management as a necessity. Frequent integrated product teams (IPTs), detailed documentation and formalized procedures should also be maintained to ensure successful configuration management.

If a stringent configuration management plan cannot be adhered to by all involved test sites, then the use of integration testing is critical in ensuring effective test management and execution. This was the case for the EW and ETE tests. For the ETE Test, exhaustive integration testing

was conducted to guarantee all test hardware, software, and interfaces could be used in their current configuration with modifications performed as necessary. For the EW Test, intensive integration testing was performed on all software before runs for record began. This was especially important because of software changes made at multiple test sites prior to the Phase 2 and Phase 3 test events. The problem with this approach is the increased need for software developers who can change software very quickly if problems are encountered. This puts a heavy responsibility on the software developers who may not be able to support such activities.

Another key point to remember when conducting integration testing for an ADS-enhanced test is to test with the entire architecture. During the SIT, a software change was made to one node and tested in a stand-alone manner. Although the fix appeared to work, when the node was tested with the entire network, the problem still existed. Just as configuration management is critical, robust integration testing with the entire network is a must.

2.2.3 Methodologies Associated with ADS for T&E

This section outlines useful procedures in implementing ADS based on steps given in the HLA Federation Development and Execution Process (FEDEP) model⁶. A more detailed version of this checklist is available in *A Test Planning Methodology – From Concept Development Through Test Execution*.⁷

STEP 1: Define Distributed Test Objectives

Activity 1.1: Identify Needs

- Activity Purpose: develop clear understanding of the problem to be addressed by the distributed test
- Activity Inputs: program objectives and information on resources available to support a distributed test
- Activity Output: needs statement

Activity 1.2: Develop Objectives

- Activity Purpose: refine the needs statement into a more detailed set of specific objectives for the distributed test
- Activity Inputs: needs statement from previous activity
- Activity Outputs: statement of the test objectives and initial planning documents

STEP 2: Develop Conceptual Model

Activity 2.1: Develop Scenario

- Activity Purpose: develop a functional specification of the test scenario
- Activity Inputs: operational context constraints specified in the test objective statement
- Activity Output: test scenario description

Activity 2.2: Perform Conceptual Analysis

⁶ "High Level Architecture Federation Development and Execution Process (FEDEP) Model, Version 1.4," 9 June 1999 available from the Defense Modeling and Simulation Organization (DMSO) HLA web site located at <http://hla.dmsi.mil/>.

⁷ Available at <http://www.jads.abq.com>. After 1 March 2001 refer requests to the Joint Program Office Technical Library, 2001 North Beauregard St. Suite 800, Alexandria, Virginia 22311.

- Activity Purpose: produce a conceptual model of the distributed testing environment
- Activity Inputs: test scenario description from previous activity, test objectives statement, and any doctrine and tactics appropriate for the scenario
- Activity Output: conceptual model that is a description of the players, their actions, and any interactions among players that need to be included in the distributed test in order to achieve all test objectives

Activity 2.3: Develop Distributed Test Requirements

- Activity Purpose: define top-level test requirements
- Activity Input: conceptual model from previous activity
- Activity Output: (1) requirements based on the distributed test objectives are directly testable and provide the implementation level guidance needed to design and develop the distributed test, and (2) requirements-based criteria for evaluating test results. Major top-level requirements that should be addressed include the following
 - Fidelity requirements for all players represented in the test scenarios
 - Interaction requirements specifying information types that must be exchanged among players to permit interactions
 - Latency requirements for the maximum acceptable latency for each pair of interacting players
 - Data reliability requirements specifying the maximum acceptable level of distributed testing-induced errors, such as dropout rate and out-of-order messages
 - Data analysis requirements including a data management and analysis plan (DMAP) detailing the analysis approach for each test objective

STEP 3: Design Distributed Test

Activity 3.1: Select Participants

- Activity Purpose: determine the suitability of individual player representations (e.g., simulations, HWIL labs, or live players/ranges) to become participants in the distributed test
- Activity Input: conceptual model developed in Activity 2.2
- Activity Output: identification of the specific player representations selected

Activity 3.2: Allocate Functionality

- Activity Purpose: allocate the responsibility to represent the entities and actions in the conceptual model to the participants
- Activity Inputs: identify participants from the previous activity along with the test requirements, the test scenario, and the conceptual model
- Activity Output: allocate requirements for the participants including any requirements for modifying existing player representations or designing new ones. The steps for this activity are as follows
 - Develop allocated requirements including the following
 - Data requirements including data rates, TSPI accuracy and smoothness, data time stamp accuracy, classification of the data and any security handling procedures
 - Data synchronization requirements
 - Real-time data processing requirements
 - Data collection/instrumentation requirements
 - Determine if modifications to the selected player representations are needed, such as
 - Simulation modifications needed to utilize external inputs

- Simulation modifications needed to generate the required outputs
- Data processing modifications needed to meet TSPI accuracy, smoothness, and latency requirements
- Facility modifications needed for a replay capability that can be used during integration testing

Activity 3.3: Prepare Plan

- Activity Purpose: develop a coordinated plan to guide the development, test, and execution of the distributed test
- Activity Inputs: initial planning documents prepared during the development of the test objectives (Activity 1.2) and the allocated participant requirements
- Activity Outputs: detailed planning documents including a detailed test plan and DMAP; a verification, validation and accreditation (VV&A) plan; and an interface control document (ICD)

STEP 4: Develop Distributed Test

Activity 4.1: Develop federation object model (FOM)

- Activity Purpose: develop the FOM (if HLA is to be implemented)
- Activity Inputs: detailed planning documents and the allocated participant requirements
- Activity Outputs: FOM and federation execution data (FED) file, if appropriate

Activity 4.2: Establish Participant Agreements

- Activity Purpose: establish all agreements among participants necessary for a fully consistent, interoperable, distributed simulation environment
- Activity Inputs: test scenario, conceptual model, and FOM (if HLA is to be implemented)
- Activity Output: revised participant allocated requirements including any requirements for additional modifications. The steps for this activity are
 - The participant interaction requirements are finalized including the following
 - Determine the data protocols to be used
 - Interface requirements including those for simulation interfaces, special-purpose interfaces, and interfaces to the RTI for HLA implementation
 - Operational issues and policies are also addressed and resolved including the following
 - Terrain database requirements
 - Post-test data management requirements
 - Test control and monitoring requirements

Activity 4.3: Implement Participant Modifications

- Activity Purpose: implement participant modifications identified in previous activities
- Activity Input: updated allocated participant requirements
- Activity Outputs: modified participants

STEP 5: Integrate and Test Architecture

Activity 5.1: Plan Execution

- Activity Purpose: define and develop the full set of information required to support the distributed test execution
- Activity Inputs: FOM and FED file (if HLA is to be implemented), test scenario, and detailed test plan

- Activity Outputs: refined and detailed integration test plan, VV&A plan, and test procedures. The steps for this activity are
 - Complete detailed network design including the following
 - Determine if data from each node will be broadcast, multicast, or unicast (transmitted point-to-point)
 - Determine if data are to be transmitted using best effort or reliable procedures
 - Determine network security approach to be implemented
 - Determine the wide area network (WAN) bandwidth requirement
 - Conduct surveys of each site to be linked by the network
 - Refine the integration test plan to include step-by-step systematic integration testing procedures that address the following
 - Procedures for verifying any simulation/range facility modifications in a systematic stand-alone fashion
 - Procedures for initially testing each WAN link separately
 - Procedures for testing each simulation-to-simulation connection with all network nodes connected
 - Procedures for testing the voice communications with all equipment and personnel as in the actual test
 - Develop detailed test control procedures and a security test and evaluation plan
- Activity 5.2: Integrate and Test Distributed Architecture
- Activity Purpose: bring all the distributed test participants into a unifying operating environment and verify that they can all interoperate to the degree required to achieve the test objectives
 - Activity Inputs: detailed test plan, VV&A plan, and test procedures
 - Activity Outputs: refined test procedures, VV&A results, and a distributed testing architecture which has been thoroughly tested and is ready for test execution. Key steps during this activity
 - Install the distributed test network
 - Select and procure the WAN to be used to link the facilities
 - Select, procure, and install the network hardware to be used including routers, channel service units (CSUs)/data service units (DSUs), multiplexers, encryptors, etc.
 - Build/procure the interfaces necessary for linking in accordance with the requirements developed during Activity 4.2
 - Select, procure, and install test control hardware and software based on the requirements developed in Activity 3.1
 - Select, procure and/or develop, and install network analysis/monitoring tools
 - Key testing steps during this activity
 - Perform compliance testing, as specified in the VV&A plan
 - Perform integration testing, as specified in the integration test plan
 - Perform risk reduction missions
 - Perform validation, as specified in the VV&A plan

STEP 6: Execute Distributed Test and Analyze Results

Activity 6.1: Execute Distributed Test

- Activity Purpose: exercise all distributed test participants as an integrated whole to generate required outputs and achieve the stated test objectives
- Activity Inputs: refined test procedures and tested distributed testing architecture from integration testing
- Activity Output: raw test results. The following considerations apply during execution
 - Pre- and post-test briefings are essential
 - Deploy test force personnel to the range/sites several hours prior to the mission to confirm that the preparations have been completed
 - Centralized test control/management and execution monitoring must be maintained, following detailed test control procedures and checklists
 - Data collected during execution are used to support both quick-look and detailed post-test analyses
 - Strict attention must be given to maintaining the security posture of the distributed testing architecture during execution
 - Conduct an after action review immediately after the test in order to gather important information from each facility, to formulate a course of action for correcting any problems, and to prepare for the next period of testing

Activity 6.2: Process Output

- Activity Purpose: post-process (as necessary) the output collected during test execution
- Activity Input: raw test results from test execution
- Activity Output: derived test results

Activity 6.3: Prepare Results

- Activity Purpose: (1) evaluate the data analysis results in order to determine if all test objectives have been met and (2) identify legacy products and make them available to other programs
- Activity Input: derived test results, along with the test evaluation criteria from Activity 2.3
- Activity Output: documented test results and legacy products

2.3 General Requirements

Issue three of the JADS charter required that the JTF identify requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future.

Issue	Objective
Issue 3: What are the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future?	Objective 3-1: Identify requirements for ADS systems that would provide a more complete T&E capability in the future.

The general requirements that are necessary if ADS systems are to support a more complete T&E capability in the future include standards for network interoperability and multilevel security, network performance requirements, expertise to support distributed testing and leadership. Sections 2.3.1-4 below discuss each of these general requirements and section 2.3.5 provides specific recommendations.

2.3.1 Standards

DMSO, the Simulation Interoperability Standards Organization (SISO), Foundation Initiative 2010, and many other government and commercial organizations are developing open systems standards for technical interoperability among live, virtual, and constructive simulations. Operational system interoperability standards are also being developed, and the distinction between operational interoperability standards and simulation interoperability standards is very slight in many cases. Multilevel security standards and distributed test control standards are areas which require additional attention. Although technical standards have a long way to go, an adequate process appears to be in place to develop them. A similar process needs to be put in place to develop programmatic standards that will support distributed testing across all phases of the acquisition process. As in the technical standards, these programmatic standards need to also support international distributed testing and training.

2.3.2 Networking

Network requirements (i.e., expected data rate, latency budget, communications protocols, control and management of the network) need to be defined early in the process. These requirements must be clearly defined and forwarded to the Defense Information Systems Agency (DISA) for evaluation of how they can best support the requirements, either through DISA common user networks (i.e., Defense Simulation Internet (DSI), Secret Internet Protocol Router Network (SIPRNET), Defense Research and Engineering Network (DREN), etc.), or by granting a waiver exempting use of common user networks in order to build a private network suitable for the requirements. It should be noted that if DISA's common user networks are used, DISA will allow connection to only one of the networks. These networks cannot be interconnected because of security, interoperability, and tariff constraints. Thus, it requires close coordination with DISA to ensure the network of choice will support all requirements.

Time is of the essence. Careful planning and consideration must be given to the schedule for implementing the communications network. On average, once the requirements are defined and a networking solution is decided upon, it will take a minimum of 120 days (if a DISA common user network is to be utilized, it could take more than 180 days) to procure and install the necessary communications circuits and networking hardware. Also, it will take a minimum of 90 days to obtain the necessary communications security (COMSEC) equipment and keying material to encrypt the data. It may take longer if a COMSEC subaccount needs to be established. In addition, time must be allocated in the schedule to install, test, and validate communications network performance. On average, JADS allocated one week per site to accomplish these tasks.

2.3.3 Expertise

Distributing testing requires expertise in many disciplines, and the JADS experience has been that very few organizations have the required depth and breadth of expertise required to efficiently conduct a successful distributed test. JADS had to develop a combination of government and contractor expertise to support each of the JADS tests. In doing so, centers of distributed testing expertise were established, but both the government and contractor expertise is very perishable. There is a critical requirement to establish persistent centers of excellence within OSD and the services to support distributed testing, or we will be required to reinvent the proverbial wheel many more times.

2.3.4 Leadership Support

Continued leadership support is required to facilitate the use of distributed testing as a widely accepted and used test tool. In particular, middle management needs to be strongly encouraged to seriously consider the use of distributed testing to support future complex acquisition programs. The previously listed requirements are areas that require immediate and sustained leadership support.

2.3.5 Recommendations

The following list of recommendations summarizes the requirements for ADS systems that are necessary to provide a more complete T&E capability in the future.

- Address ADS approaches in the test and evaluation master plan (TEMP).
- Focus on the ability of ADS to overcome any identified test limitations.
- Program managers and operational test agencies (OTAs) should embrace and implement STEP and SBA. ADS is an enabling technology for STEP and SBA.
- Use the IPT/integrated product and process development (IPPD) process to facilitate utilization of assets across phases of development including requirements definition, engineering, manufacture and development, test and evaluation, operations and training.

- Mid- and upper-management should encourage/require T&E vision beyond the scope of individual test events and specific systems.
- When making an ADS go/no go decision, compare ADS-enhanced testing costs to the costs of the alternative method(s).
- Use JADS-developed ADS cost guidance to help identify the optimal mix of ADS enhanced testing and traditional means of testing.
- DoD should develop infrastructure to reduce the costs of linking.
- Use an ADS test environment over the life of a program.
- Incorporate ADS into the curricula of formal T&E and acquisition schools.
- DoD should nurture groundbreaking programs, such as Foundation Initiative 2010, Joint Strike Fighter.
- Use JADS-developed ADS methodologies such as test planning, verification and validation.
- Each organization using ADS should plan for a centralized test control and analysis capability. Such a facility can be low cost and located anywhere. In addition to test control, it can be used to enhance real-time data analysis and test efficiency.

3.0 Lessons Learned

Near the end of the JADS program, we came to the realization that the term “Advanced Distributed Simulation (ADS)” was potentially misleading when used in the context of T&E. The word “simulation” is something of a turn off for testers, because they are sharply focused on collecting real data whenever they can. In fact, distributed architectures can be used effectively to support actual testing. A SUT can be incorporated into a distributed architecture and subjected to valid stimuli that can originate at a number of remote sites. The collection of stimuli may indeed create an “artificial environment” which is perceived by the SUT, but if the stimuli are valid, real performance data can be collected on the performance of the SUT. That is testing. (As an aside, even in traditional testing, the test environment is, more often than not, artificial.) The fact that a stimulus originates at some distance from the SUT location is immaterial so long as it is a valid stimulus. Distributed architectures can provide robust test environments and offer opportunities to conduct concurrent, rather than sequential test events, that generate actual SUT performance data. Distributed testing, as we see it, is a subset of ADS. There will almost certainly be opportunities to use ADS as a simulation tool in support of acquisition programs, but there will also be potential benefits to using distributed architectures as genuine test tools. In this section the lessons learned from all three JADS tests are compiled under technical and programmatic categories. In some cases the lessons learned apply to more than one category and thus appear multiple times. For each category an attempt was made to distill the lessons learned in that category into some key findings. The process to do this was very subjective and the reader is encouraged to perform his/her own assessment.

3.1 Technical

3.1.1 Simulations

- Careful design and thorough integration testing are required regardless of whether you’re developing and linking a new simulation or linking an existing stand-alone simulation.
- As in the SIT LSP, a major lesson learned is that stand-alone simulation facilities (for live, virtual or constructive entities) can require significant modifications before effective linking is possible.
- Simulations, when used in distributed testing, should be carefully planned and developed. Using reliable simulations is important for a successful test.
- Some problems existed in the robustness of the Digital System Model (DSM) software that resulted in reliability problems with the DSM and its federate. Although a hindrance, the DSM performance was adequate to collect the needed data. Better software design, quality assurance, and testing would have uncovered the reliability, logic, and buffer limit issues seen in the test execution.

3.1.2 Interfaces

- For the foreseeable future, distributed testing will utilize simulations that were not designed to work together. In most cases it is more cost effective to develop interface units than it is to

modify existing simulations. Careful design and testing of these interfaces are required to ensure they perform the desired functions without adding large processing delays.

- Accurate coordinate transformations are necessary. They must be verified and validated at each site and then revalidated during end-to-end testing as early as possible in the test phase.
- Network interface units (NIU) need improvement. NIUs are necessary if two nodes cannot communicate directly in a common language. They can be a major source of both errors and processing delays. Better direct user control of the content of the data and network communications is needed.
- Linking of facilities using ADS can require significant facility interface hardware and software development. ADS implementation is not "plug and play," at least for some time.
- Additionally, linking may require special purpose interfaces to accept inputs in real time. Development of such units must be factored into test planning.
- Latency variations were significant. Processing delays were the primary culprit here.
- Key interfaces need realistic integration testing. Replaying data from a recorded mission worked well in most cases (and was most cost effective); however, some integration testing required a live mission.
- Distributed testing often requires linkage among dissimilar facilities, network equipment, and simulations. However, careful planning can significantly reduce the potential for difficulties arising from network interface problems.

3.1.3 Networks

- Distributed testing applications have unique and sometimes stringent network performance requirements for latency and latency variation. There are many design decisions that impact network performance. Special instrumentation and thorough testing are required to ensure the network is meeting performance requirements.
- Common ADS-related hardware and software are needed. In the LSP, it was difficult to get the ADS network to behave in a uniform fashion because of the many different types of interface hardware, communications equipment (routers), and interface software versions. Latency variations were significant. Processing delays were the primary culprit here.
- Early definition of network requirements was very advantageous. This was a major lesson from the LSP that JADS took advantage of.
- Federations should experiment with different transport modes to determine the optimum mix of transport modes. In the EW test federation performance varied as the mix of reliable and best effort data changed. Through trial and error, fewer problems with latency and data loss were noted if less reliable traffic was published within the federation. However, this was a subjective opinion because no tools were available to test the performance envelope of the architecture. Federation performance was poor when integration testing started. RTI developers should have tools or performance measurements to guide federation developers as they design and integrate their architectures. The link health messages were required to be published as best effort to correct this problem. This change was made late in the integration effort to further tune the architecture with the real federates. Link health check messages were published best effort during both ADS testing phases.

3.1.4 Instrumentation

- Special network instrumentation is required to monitor network performance during both development and test execution. Time stamping and synchronization are unique aspects of distributed testing that required special attention. Live players also have unique instrumentation requirements for distributed test applications.
- Time sources must be synchronized off the same time source and then must be validated at each test site prior to project operations to ensure accurate, synchronized time is precisely recorded at each test site.
- Special test equipment is needed for checkout and verification of the ADS architecture. Without this equipment, trial and error becomes the norm when (not if) problems crop up.
- Changes and upgrades to aircraft instrumentation delayed development. Specially instrumented aircraft were required to support the LFP flights. Because of the small number of such aircraft, the LFP schedule was very sensitive to periodic aircraft phase inspections, software upgrades, and higher priority missions.
- In the LSP merging several TSPI sources was advantageous. Real-time aircraft inertial navigation system (INS) and GPS data were combined to calculate more accurate kinematic estimates. When combined with the ground radars, solutions of one to three meters in position and one meter per second in velocity were achieved.
- Time sources must be synchronized using a "master clock" and then validated at each network node.
- Special test equipment and networking tools are necessary for distributed testing. The tool set must be able to rapidly isolate the specific cause of network and ADS/DIS problems.
- In the EW test TSPI data losses among platform federate, the DSM, AFEWES, and test control federate (TCF) occurred frequently during federation integration. JADS and DMSO investigated this problem. A work-around solution was a fixed join process for federates prior to each test run. After the solution was implemented, data losses among the DSM, AFEWES, and the platform federate were still observed. These losses manifested themselves in the apparent hovering aircraft observed in the federate integration test (FIT). It was not clear what caused the data loss, but dead reckoning aircraft position provided an acceptable solution. This data loss coupled with the dead reckoning implementation at AFEWES was the suspected cause of an extremely large miss distance value on one missile shot. RTI bundling of federate data for transmission made troubleshooting data flow and transmission problems more difficult. Our tools assessed hardware performance only.
- Instrumentation for federation performance evaluation used in the EW Test Phase 2 was inadequate. It lacked the ability to examine data passed between RTI instances. Best effort data could be dropped by the network without notification or without any faults reported by the hardware. Phase 3 network instrumentation must be expanded to include network sniffers to monitor network traffic between the sites.
- In the EW test JADS was highly dependent upon time synchronization of all federate computers and software. Any requirement for synchronization requires the ability to verify that the requirement is being met. For example, if one millisecond synchronization accuracy is required, then a capability to measure time between two computers at one millisecond precision is necessary. However, software tools were not available to measure accuracy at that level. In fact, testing time synchronization across the federation was more art than science. Even with time synchronization and the time cards implemented in all computers,

instances were noted where time synchronization "slipped" affecting latency measurements. A few occurrences of time synchronization problems across the federation were observed requiring JADS to research particular runs after daily testing. JADS consistently followed documented time synchronization procedures and hardware settings. Site support personnel were relied upon to implement procedures and verify settings daily.

- If you are going to use hardware for time synchronization (e.g., BanComm cards) obtain time directly from the card. You may have to write device drivers to get this capability. You also need to resolve how you will measure time synchronization differences. However, other alternatives exist. The network time protocol (NTP) software (xntp for UNIX hosts; NTP time for PC hosts) provided an easy-to-use method to synchronize system clocks to a time source. In other JADS tests the system clock could be kept within one millisecond of the time source. The software does require time and attention to reach this level of performance. However, it keeps statistics on how well it is keeping time and it's free.
- In the EW test ADS was not able to completely solve time synchronization issues in the federate computers using time cards. In theory, the hardware cards should provide the most accurate time synchronization available. In practice, some implementations proved more robust than others did and verifying time synchronization across a wide area network (WAN) proved to be elusive. The most effective configuration of the BanComm cards was not implemented for time synchronization on either the UNIX-based or the personal computer (PC)-based hosts. In addition, there were problems with the BanComm hardware, BanComm software, and with one of JADS contractor's attempts to write software to use the BanComm cards. The software executing on the Silicon Graphics, Inc., (SGI) O2s read time directly off the BanComm cards via the JADS contractor-developed driver software. This provided the most accurate time synchronization solution. However, the method used to obtain time information (via overloading of an IRIX operating system call) had the limitation that it did not provide any means for the federates to query the BanComm card as to whether it was actually using the Inter-Range Instrumentation Group (IRIG)- B time code input signal (the desired state) or free running using its internal crystal oscillator. However, on the PCs, BanComm-provided software was used to synchronize PC system time to BanComm card time. This was not very accurate, and in some cases, time on the PCs was off by as much as 60 milliseconds. In addition, this software did not synchronize the system time immediately when Windows 95 or Windows 98 was started or restarted, which apparently caused several aborted runs because of the time on an ADRS PC being unsynchronized. Also, for the PCs, there was still the problem of determining when the BanComm lost its signal and was free running on its internal oscillator. Finally, JADS lacked an adequate method of detecting time synchronization problems in real time during federate execution runs. Only in cases where severe symptoms were produced by time synchronization, problems such as bursts of platform federate live entity state and threat performance messages caused by a start time in the past (for platform) were noticed immediately and corrected. Data that were time stamped on the PCs (ADRS and DSM) were only judged "good enough." There was a lot of variation in the time value that originated on the PCs. This did not impact the ADRS PCs as they only used the time stamp in the start command, telling all federates to start at some time in the future. However, the DSM PC did exhibit some odd behavior that affected calculation of jammer response times.

3.1.5 Test Control

- There are many unique aspects to distributed test control that require a carefully selected mix of central and local control. The central control facility must have the display and communications capabilities to know total system health in real time. Total system health includes not only the status of the real, virtual, and constructive players but also the data processing and collection systems and the system synchronization mechanism. Real-time processing of system data is essential to efficient test conduct.
- Test communications requirements must be addressed early in the test planning phase. This is necessary to ensure effective communications during the test. Also, a linked test should have multiple (more than two) communications nets with easy, selectable access to all the nets from multiple locations within the site. Finally, the capability for secure video teleconferencing pays big dividends during planning, coordination, and post-test debriefs.
- Local (on-site) test monitoring/control should be used prior to remote test monitoring/control.
- Tight control of the aircrew is not desirable. Give them the critical parameters and switchology to meet the test objectives and allow them to make tactical decisions, fly the "aircraft," operate the weapon system, etc.
- Several subnetworks should be used for voice communications. Three voice communications networks were needed to support more than 30 people at various locations, and a fourth network would have further aided decision making.
- Two-dimensional displays were needed at each node; they greatly enhanced the situational awareness of the participants.
- Have a centralized test control center with test controllers who are extremely familiar with the test and network configuration.
- Personnel involved in a distributed test need to understand the "big picture." When people are geographically separated, it becomes easy for them to focus on their own individual portion of the test. When problems arise, personnel who understand the entire test and the overall network will find solutions much faster.
- Operator boredom with the repetitiveness of test runs at AFEWES may have contributed to afternoon run differences. JADS attempted to minimize turn-around time between runs. The time between runs from start time to start time was usually between 6 and 8 minutes.
- Detailed planning for run management is necessary before testing commences. During daily testing, a run matrix was used to determine which runs were executed; what procedures were used to start the federates, models and simulators; and to initiate the run, stop the run and shut down of the federates. The work done during preliminary testing (e.g., federate acceptance test [FAT], federate integration test [FIT]) provided a repeatable methodology for orderly federation operation that was used for the formal test. Nonetheless, problems were frequently encountered, errors were made, and unanticipated issues arose.
- During test runs, the TCAC test controller was highly dependent on ADRS for federation and scenario status monitoring. Analysts were highly dependent on the ADRS emitter state history display for monitoring jammer/threat engagement details. JADS found the analysis federate scenario visualizer to be a solid capability. While it provided an extra set of graphical displays of the unfolding engagement, it also provided real-time feedback of the EW Test MOPs. Anomalies in miss distance and response times could be instantly assessed, which was an added capability separate from ADRS. The analysis federate could not take the place of an ADRS machine for Phase 3, but it could support troubleshooting of anomalies

seen during the runs. Without the analysis federate, problems seen could be at AFEWES, ACETEF or in one of the many federates run at JADS. The analysis federate aided in identifying the source of the problem. If presented with extremely limited time and manning, the analysis federate could be eliminated with only a small impact to test execution. It was not critical to the function of the test but did provide an extra source of examination of the run execution. The greatest benefit of the analysis federate was the real-time assessment of the EW Test MOPs and the integration of the aircraft profile with the threat mode status. If tasks needed to be combined, the analysis federate would need to be updated to assume the responsibilities of the second ADRS machine.

- JADS EW voice links were conducted using conference calls with open lines to AFEWES and ACETEF. This capability continued to evolve as command and control requirements evolved. JADS used head-mounted earphone/microphone equipment and experienced numerous problems with hearing and being heard across the network. Most problems were alleviated with equipment familiarity and experience. Batteries had to be replaced frequently. The FAT and FIT demonstrated shortfalls in the voice communications that required more equipment at each facility. As the number of instruments increased, testers became very busy coordinating status, communicating test information, and controlling run execution. Consequently, message transmission length had to be minimized; external background conversations avoided; and test problem troubleshooting had to be done via a separate line. ACETEF had some telephone instrument problems. JADS used Phase 2 conference call initialization methods during Phase 3 and included more formalized discussion procedures and protocols.
- JADS refined voice protocols for acknowledging readiness among sites and starting/stopping runs for EW Phase 3. Further review of link health status confirmation procedures and network health check impacts was needed. JADS improved situational awareness for network health and readiness across sites and formalized the procedures as necessary.
- The health check was inadequate for monitoring JADS EW federation status for several reasons. First, its time scale, which was about 20 seconds before any indication of a problem, was too long for a real-time federation. Second, because it sent its messages via TCP/Internet protocol (IP), this system could not detect a problem for federate messages sent via RTI best effort, i.e., UDP/IP-based protocol, unless the underlying cause of the problem affected both of those protocols. And third, the RTI did not time stamp and log these messages, so they were only available in real time. JADS did not use this as a primary indication of federation health, so no changes were required. Future federations should investigate RTI tuning features (e.g., runtime infrastructure initialization data [RID] file parameters) or other RTI management features (e.g., management object model calls) if the federation doesn't implement its own health monitors like JADS did.
- The JADS link health check (LHC) scheme during the EW test provided reasonable insight into federation health once it was understood. Analysis showed that there was a high correlation between the loss of LHC messages and most, but not all, events that involved the loss of other federate messages sent best effort and/or the delay of messages sent via RTI reliable, TCP/IP-based communications protocol. Due to its 1 hertz message frequency, the LHC system sometimes missed best effort data loss events lasting less than 1 second, but those events apparently did not cause any simulation problems. Since the LHC system sent its messages via the best effort protocol, it could also not detect short-duration problems that affected only the TCP/IP connection used for reliable protocol between two federates.

Perhaps, the most interesting result from the post-test analysis of the LHC messages was that the LHC system detected selective, one-way best effort data losses between federates that may be a symptom of problem(s) with the RTIs use of IP multicast groups. For the runs during which these problems were observed, the losses were selective because LHC messages (and usually other federate messages sent best effort as well) were lost between one or more federates at JADS and the federate at another test node but not between the remaining JADS federates and that remote federate. The losses were one way because the LHC messages between the federates experiencing the problem were lost in only one direction. Typically, during such events, there was no delay in the flow of reliable messages between those federates, if any reliable traffic was present. It was difficult to understand how network or network hardware problems could produce such selective, one-way data losses. While LHC as implemented has limitations, it was sufficient for JADS in Phase 3. Future federations should consider the limitations noted if they choose to pursue a similar health monitor scheme for their federation.

- Test design should include as much real-time analysis as possible. This will increase the success rate during test execution and minimize time required to repeat test activities if the equipment problems are not noticed until after test completion. Future testers should also consider possible actions when problems are discovered during test execution. The decision to stop testing until the problem is fixed or continue and account for the problem in the results is a difficult decision that should be considered long before test execution begins. During the various test phases, real-time analysis became more and more crucial to the successful execution of the test. EW Phase 3 was largely impacted by the need to accomplish as many successful runs as possible in the least amount of test time. Without the ability to observe and critique performance from the various federation participants, the test time would have been lengthened or the useable test data collected would have been significantly decreased. ADRS and site observers were vital to correcting operator actions and clarifying the rules of engagement. SUT observers were also critical in determining if the SUT was performing as desired as the test was executed. Network observers were also needed to observe the performance of network equipment during test execution. The ability in all phases to watch threat performance, operator performance, and SUT performance became a cornerstone to successful test execution. The real-time analysis supplied vital information to the test controller who could ask questions about specific equipment or operators as soon as problems were noticed. During Phase 3, this capability corrected severe operator training problems at AFEWES and SUT problems at ACETEF that allowed many runs to be saved in the final data sets.
- ADRS equipment crashes and reboots frequently disrupted testing and slowed the rate of JADS EW testing. The problem was moderated during Phase 2 by adopting new procedures like rebooting each time a computer was idle. SGI O2 to PC interface software developed for our federates (called the JADS communicator) would leave a communications socket allocated after ADRS crashed, so additional time was lost waiting for the socket to reset. Procedural speed for starting ADRS contributed to the problem. It was very important that the computer be started in a specific sequence in the TCAC. The action adopted by JADS was to analyze the run logs for reliability problems to determine where changes in processes and communication could improve Phase 3 operations. A memory leak problem was detected in the ADRS computer that resulted in many software crashes caused when the

system would run out of available memory. This was solved by the frequent reboots. It was also marked for correction before Phase 3.

3.1.6 Software Development

- Testing in software quality is not generally possible. Poorly designed software rarely emerges from testing in any better condition. Conversely one should not take the position that well planned and developed software does not require testing. The development and coordination of complex models to support distributed testing requires extraordinary attention to configuration management issues. The added complexity of distributed testing over stand-alone applications makes following proven software engineering standards and procedures critical. Configuration control was particularly problematic and required extraordinary attention.
- Some problems existed in the robustness of the EW DSM software that resulted in reliability problems with the DSM and its federate. Although a hindrance, the DSM performance was adequate to collect the needed data. Better software design, quality assurance, and testing would have uncovered the reliability, logic, and buffer limit issues seen in the test execution.
- Configuration control is essential. This one obvious area was one of great challenge for all three JADS tests considering the many sites involved and the multiple uses of each site.
- Configuration changes on tools (analysis federate, ADRS display, DSM joining process, AFEWES dead reckoning algorithms) could have severe impacts. Configuration changes, even seemingly trivial ones, must be coordinated at all levels. JADS stressed configuration management procedures for Phase 3 and enforced their use.
- Acceptance testing of federate software is a recommended practice. These acceptance tests should be designed to (1) test the software in its intended mode of operation, and (2) test all requirements of the software. It can encourage the developer to fix problems before they impact the test. It provides an excellent mechanism for supporting the V&V of the federation by proving the federates are built correctly and satisfy the needed simulation requirements. Additionally, acceptance tests provide a clear event to which configuration management milestones can be tied. It was JADS experience that software acceptance testing of ADS components in their stand-alone mode did not uncover problems encountered once they were integrated into the ADS environment. Originally software acceptance testing was not planned as part of JADS software development effort for the EW test. Formal testing was thought to be too costly and too late in the development process to be effective. JADS planned to use in-process reviews with each developer to gain insight and cross communication to get the right software products developed. However, when JADS was unable to gain insight into the software development and received obvious indications that there were flaws in some of the software items, JADS elected to use acceptance testing. Because of cost and schedule constraints, the scope of these tests was limited to the development environments and to the test sets that were available at the time. These acceptance tests did not address all software requirements. For example, the acceptance test did not consider the operational modes of the jammer DSM as executed in the ADS environment. The acceptance testing also did not stress the model to the level of execution encountered within the ADS test environment. This resulted in a model that functioned well in stand-alone mode but was marginal when integrated into the ADS environment and operated according to the test procedures. Acceptance testing provided a more solid basis for

V&V efforts. The limited acceptance test addressed several key requirements such as correct calculation of received power and correct calibration. The results of the acceptance test were available to the accreditation board to determine if the software met JADS' needs. Finally, acceptance testing allowed a convenient point to establish configuration baselines and to transfer control of those baselines to JADS. Acceptance testing was better planned in Phase 3 of the EW test even though we still had limited test cases and tools. The new software was acceptance tested as part of the V&V plan. Formal baselines were established after completion of the acceptance tests.

- Frequently, the government only knows in general terms what is needed to execute tests in a geographically distributed environment. Test design must mature to identify the specific capabilities that each facility will provide before specifications are created. This generally precludes creating good performance specifications prior to contract award. Sufficient tasking must be included in the SOW to ensure that government interests are covered and the lead from the contractor has a leverage tool to use to ensure the work is executed on time with good quality. Sequential contract awards may be used to mitigate risks associated with loose SOWs. JADS learned from the planning and execution of the EW test that abbreviated statements of work (SOW) and reduced deliverables resulted in differences in expectations between contractors and the government. The loosely defined SOW allowed the analysis team to continue to refine software requirements for a critical piece of software necessary for the test execution well beyond the date it should have been finalized. Several measures of performance were modified from the non-traditional calculation to help measure ADS effects. This proved more difficult than expected. Since delivery schedules were not clearly defined, the contractor permitted these discussions to go on well beyond the time needed to code and test the software to meet the government's expected delivery date. All parties were trying to get the best insight into ADS effects on the EW Test measures while balancing impacts to the software. The problem was resolved when the government program manager froze software requirements and provided the contractor a specific delivery date. A second impact was related to the level of on-site test support. The loosely defined SOW allowed the contractor to reallocate on-site resources earlier in the test design to support other test activities. The reallocation was discussed with the government; however, the impact to on-site support during Phase 2 was not explicitly negotiated. As a result, the government received less support than expected. Once the software requirements were frozen, the updated software was delivered in time for test execution.
- Strict contractual requirements may be needed for organizations where the development processes are not well understood. Critical software should be developed by companies with proven subject matter experience and sound software development practices. Well-defined quality software practices were important for any software development; however, when working with multiple facilities in an ADS test, strict adherence to practices were necessary to ensure success. In addition, processes for assessing software quality (e.g., independent acceptance test) were needed to ensure that each ADS component operated as expected. No plan existed to ensure software quality for the JADS EW test. JADS originally relied on each developer's internal practices to produce quality software. JADS attempted to gain insight into software development at each facility but failed. Post-development quality measures were implemented to inspect delivered software. Several problems were identified with the DSM that should have been identified earlier in the software development process. Specifically, software requirement specifications (SRS) and the interface control document

(ICD) were sometimes misinterpreted by the developers. These problems could have been found by closer monitoring of the software development process, particularly in the area of requirements management. As we learned these valuable lessons JADS became more involved in the software development process of the remaining federates. Daily contact prevented several errors from going undetected and resolved the problems before the actual test event.

- Perhaps the most important lesson learned from EW Phase 2 and the preparation for it was the critical importance of careful planning and preparations at the earliest stages of the program. It is better to avoid problems, since there may not be enough time and/or money to find and fix them later. This seems especially true for ADS programs. The nature of ADS brings multiple facilities together, each having their own development style and practices and each bringing a potentially different understanding of the problem. This is very similar to having multiple facilities working together to develop a single software package. Any actions that reduce ambiguity in the interface design will reduce the risk of the program. This is very important for ADS-based tests since it may be difficult to slip test schedules when multiple facilities are involved. Hence, the importance of a good ICD and enforcing the same methods of compliance from the start of software development. An ICD was developed for the JADS federation to guide software developers. Two problems were identified relating to this ICD: (1) nonconformance to the ICD and (2) differences in interpretation of complex concepts. Prior to the test, the description of the coordinate transformation was agreed to be acceptable by all participants; however, facilities developed different implementations of the software when coding was finished. The problem was finally resolved when JADS provided sample transformation pairs for testing each facility's algorithm. These sample data points should have been included in the JADS ICD to avoid confusion. In some instances software was developed that did not conform to the ICD. Because of the lack of detailed acceptance testing these nonconformance problems were not found until very late in the integration process. As a result, decisions had to be made either to bring the software into conformance or to change the ICD in order to maintain test schedule. For example, problems with the federate message sequence numbers illustrate both the test and post-test impacts. For each instance of a simulation object, the federates should have used sequence numbers in outgoing messages starting from 1 and incremented by 1 for each successive message. However, because of a combination of ambiguous ICD wording and lack of early ICD compliance testing and enforcement, the TTH and AFEWES federates transmitted message sequences that did not conform to the same sequence numbering scheme. During Phase 2 test execution this became a problem with the DSM PC's real-time error checking for incoming source mode change (SMC) messages. The sequence number was used by the DSM to detect missing and out-of-order messages. Since the sequence numbers were not set correctly, the error reports were misleading and ineffective. During the post-test analysis, improper message sequence numbers for several message types made it more difficult to detect and analyze runs with data loss and latency problems for the ADS analysis process. In particular, it greatly complicated the calculation of overall latencies for the critical combination of outgoing SMC messages and the corresponding jammer technique command messages generated by the DSM. To correct for these problems message sequence counters were corrected for both the TTH and AFEWES threat federates for Phase 3. Wording in the ICD was changed to be less ambiguous.

3.1.7 Integration

- Time sources must be synchronized using a "master clock" and then validated at each network node.
- Get SUT experts involved from the beginning.
- A stepped build-up approach should be used. First, a systematic checkout of the stand-alone simulators (live, virtual or constructive) is needed. Next, direct (non-DIS) links should be used during test build-up. Finally, structured testing of the network must be performed prior to, and independent of, the linked testing times and the simulation laboratories to validate transmission/reception rates, bandwidth utilization, latency, data transmission and reception, etc., prior to commencing project test periods.
- Key interfaces need realistic integration testing. Replaying data from a recorded mission worked well in most cases (and was most cost effective); however, some integration testing required a live mission.
- Use risk reduction tests for integration. A building block approach was used successfully to check out interfaces at the lowest level, then one or two resources at a time were added to integrate the linked configuration. These risk reduction tests were also useful for developing analytical tools.
- Use a stepped approach to testing where each successive ADS test builds on the success of earlier tests. This "test, analyze, fix, test" approach, in concert with structured, independent testing of the network, will greatly improve the chances for successful distributed testing.
- Risk reduction testing prior to actual test execution provided effective rehearsals and was helpful for troubleshooting.
- The FAT and FIT series of federation tests were invaluable for establishing EW Phase 2 procedures within the TCAC and with AFEWES and ACETEF. However, personnel were added or changed locations for test execution which impacted test rehearsal learning. The action adopted by JADS was to plan appropriate test rehearsals and comprehensive integration tests for Phase 3.
- Distributed testing requires strong systems integration and systems engineering. There are important considerations in the planning process that are not well understood and therefore may lead to unanticipated costs. This responsibility is difficult to manage by participants supplying items to be integrated. If the sponsor is unable to provide the expertise of a systems engineer and integrator, an independent source should be used. Subject matter experience and knowledge of computers and communications technology are essential for the systems integrator. JADS assumed the lead systems engineering role throughout the JADS EW Test. During Phase 2 execution, the responsibility of system engineering unofficially transferred to other IPT members. Quite often, IPT members were also responsible for performing development tasks and delivery of several key software elements. This made it difficult for these IPT members to remain unbiased and independent during integration. The systems engineer needs to objectively identify and aggressively resolve problems. Using an independent systems engineer does this best.

3.1.8 Data Analysis

- There are two unique aspects of distributed testing that affect data analysis and must be planned for early. The first is the requirement to do real-time data analysis to support test

control and test conduct. The second is that distributed testing generates large amounts of data in a short time. Without careful planning and testing of the entire data collection, processing, and analysis process, the analysts will be either hopelessly lost or hopelessly buried in data.

- Test design should include as much real-time analysis as possible. This will increase the success rate during test execution and minimize time required to repeat test activities if the equipment problems are not noticed until after test completion. Future testers should also consider possible actions when problems are discovered during test execution. The decision to stop testing until the problem is fixed or continue and account for the problem in the results is a difficult decision that should be considered long before test execution begins. During the various test phases, real-time analysis became more and more crucial to the successful execution of the test. Phase 3 was largely impacted by the need to accomplish as many successful runs as possible in the least amount of test time. Without the ability to observe and critique performance from the various federation participants, the test time would have been lengthened or the useable test data collected would have been significantly decreased. ADRS and site observers were vital to correcting operator actions and clarifying the rules of engagement. SUT observers were also critical in determining if the SUT was performing as desired as the test was executed. Network observers were also needed to observe the performance of network equipment during test execution. The ability in all phases to watch threat performance, operator performance, and SUT performance became a cornerstone to successful test execution. The real-time analysis supplied vital information to the test controller who could ask questions about specific equipment or operators as soon as problems were noticed. During Phase 3, this capability corrected severe operator training problems at AFEWES and SUT problems at ACETEF that allowed many runs to be saved in the final data sets.
- Effective data management is needed as ADS can generate mountains of data. A comprehensive plan will clearly identify the data to be collected at each site, on-site processing of the data, and data to be transferred to the analysis center.
- Adequate time must be allowed for data analysis between test events. Analysis procedures should be rehearsed to better understand the amount of time needed for this analysis.
- Analysts should become very familiar with the analysis software products very early in the test process. If possible, products should be chosen that automate and complete the most work with the least amount of intervention and modification from the analysis team. If multiple products are deemed necessary, the amount of flexibility in each application to read files from other applications is very important. Some consideration should be given to building a specific process that will accomplish all pieces of the analysis process within a single application. Training analysts on the selected applications should also be accomplished early in the analysis process. During the analysis of the test data, the lack of integration among data analysis products became troublesome. For the OAR test, the conversion utilities used to create files for reduction in ADRS from the OAR data files were time consuming. Furthermore, in the analysis of HITL, Phase 2, and Phase 3 data, the gathering of summary statistics and the execution of the correlation process were also very time consuming because the entire process could not be done within a single application. With the additional work needed to change formats of data among the various pieces of the ADRS software, the summary statistics and graphical representations were completed using Microsoft® Excel. Exporting the data to Excel was time consuming in itself but resulted in

the ability to modify data sets and greater flexibility in creating graphs and sorting individual data sets. Further work was required to perform "correlation" using Statistix because Excel did not perform the Kolmogorov-Smirnoff test. This was also very time consuming and lengthened the time needed to complete the analysis process.

- Future testers wishing to perform "correlation" should allow for engineering assessments from SMEs to be able to obtain useful information from the correlation process. The ultimate question between data sets collected from two different test phases is, "How much difference is too much to tolerate?" The EW "correlation" process provided for very poor results when correlating the different phases of the EW Test. The student's t and F tests used to assess data sets means and variances were very rigid and provided for very low probable values (P-values) for most data sets. These tests examined if the two data sets considered came from exactly the same population. The P-value was calculated from the means, variances, and number of samples in each data set. At low data sample counts, these tests were more flexible in determining the P-value between the two data sets. In these cases, a small difference in means or variances did not always generate low P-values. However, as sample count increased, the tests became more and more rigid. As seen in the J/S correlation tables, the extremely high sample counts provided for P-values of .0000 when the data sets graphically aligned quite well. The Kolmogorov-Smirnoff test was not quite as rigid as the t and F tests, but the results were almost equally poor. This can lead the test manager into a false sense of failure because data sets between test phases did not correlate. Based on the requirements of the "correlation" process, the tests could be relaxed to provide more insightful information to the test manager. For instance, when the mean miss distances for missile shots for a threat system are 24.0 and 25.5 feet between two test phases, the correlation tests gave moderately low P-values. However, the sets should be considered equal if the blast radius of the missile is 30 feet. Engineering assessments were needed to determine how much difference between two data sets was acceptable before the data sets were not considered to be from the same population. The current process did not provide meaningful insight into the threat, SUT, or operator performance, nor did it allow the tester to assess if ADS affected the MOP results.
- System data should be validated as early in the test process as possible. Validity was the lesser of the two problems. Repeatability should be checked during the analysis of each phase of test data. If repeatability cannot be guaranteed and proven, more data should be collected, if possible, or the analysis reports should reflect the non-repeatable nature of the data sets. When ROE or more samples can not make the data become repeatable, the correlation process should not be used on that particular data set. The "correlation" process assumes the collected data from the different test phases are valid and repeatable. If the data were invalid, they were not useful to the test manager to judge SUT, threat, or operator performance. If the data were not repeatable, the "correlation" of such data ran the risk of obtaining both false positive or false negative "correlation" simply because of the luck of the draw with the collected data. Post-test analysis revealed that not all the data collected were repeatable. The validation process only asserted validation by the participating agencies without explicitly checking the collected data by subject matter experts. Both of these problems affected the poor results of correlation between the different test phases. Because repeatability and validity were assumed pretest and not explicitly checked, the results of the correlation process should not be used in the assessment of system performance. This was

only one of many factors leading to the discredit of the correlation process and calling for modifications to future tests where correlation is used.

- MOP definitions should be modified in future tests to assess fewer components, or the data should be collected in a manner that allows the analysis team to better determine the individual effects of each source of variance. Without the ability to perform this function, it will be troublesome to make definitive and valid statements about the ADS effects on EW testing. During the analysis process, it became very difficult to assess the individual variance sources in the MOP data sets. Operator variance, system performance, and ADS performance, for instance, affected missile miss distance. Determining which of these sources caused the largest amount of variance was difficult to find and almost impossible to assert. Other MOPs, such as correct threat identification (ID), response time and correct ECM technique response time, were largely affected by data latency. However, without the data sets being collected in two different manners (both with and without latency included), it was very difficult to determine if the lack of "correlation" was due to data latency or system performance. Many other instances were available that showed the mixture of different sources of variance and their convoluted influence on the collected data sets. It was nearly impossible to point directly to the source of variance for many MOPs. This diminished JADS ability to determine the effects of ADS on EW testing. Because the MOPs were modified to assess multiple components of the test (e.g., ADS, threat, SUT, and operator performance) the ability to comment on the specific effects from each component was greatly diminished.
- For future tests, non-ADS effects should be understood well before test execution in order to assess each component. Modifications should be made to ROE, MOP definitions, or the engagement scenario to better control the non-ADS effects or to at least be more able to separate the effects of the different sources of variance. Without the separation and control of the ADS and non-ADS effects, correlation between data sets may still prove to be an impossible task. Based on the analysis performed on the test data, it was discovered that non-ADS effects caused the largest amount of variance in most of the MOPs. Operator variance was the largest source of variance by far. Because the operator's choices on when to switch modes, how well to track, when to fire missiles, etc., affected the test data, constraining this was a very difficult problem. Even among the expert operators, variance from the operator was still larger than any variance caused by ADS effects such as data latency, data loss, data corruption, etc. Furthermore, threat differences and SUT differences among the different test phases also contributed to the variance in the data sets. Without constraining the non-ADS effects on the MOPs collected, it was quite difficult to determine the ADS effects on the MOP data. Since the primary objective of the EW Test was to assess the ADS impacts to EW testing, the success at this project were mostly qualitative results based on the understanding of the MOP definitions and the qualitative results seen through the various test phases.
- Future testers should attempt preliminary testing to determine if the MOP definitions selected allow the expected results to be collected from the test execution. More so, the determination of which components will be assessed should be determined very early, and the test design should be modified to accommodate these assessments. The MOP/MOE definitions used in current EW testing allowed for many various effects to be combined into a single measure. Missile miss distance combined the effects of SUT, threat, operator, and ADS performance, which made it nearly impossible to determine the individual effect of ADS impacts. Other

MOPs, such as correct threat ID response time and correct ECM technique selection response time allowed the ADS effects to be quantified but only if the data were collected so the ADS effects could be explicitly removed from each data sample. Most other MOPs did not allow for an accurate assessment of ADS impacts to EW testing. Without the ability to separate the individual effects of ADS impacts, the successful completion of the JADS tasking to determine the utility of ADS for various types of testing was weakened. Because the MOP/MOE definitions combined the different sources of variance, it was only possible to make educated guesses about the impacts of ADS to EW testing. In very few cases was it possible to effectively determine the ADS effects on the performance of the various components, and without quantitative data to back JADS claims, the results and interpretations of ADS utility were subject to individual opinion.

3.1.9 HLA

- HLA was adequate to support the EW Test, but it required a lot of tuning and trial and error testing on the part of JADS and DMSO. Better documentation that provides insight into the inner-workings of the RTI would help. Thorough instrumentation is required to track and isolate problems between the network and the RTI. The T&E community needs to actively participate in the Architecture Management Group to promote the development of HLA standards and products that meet the needs of the T&E community.
- When JADS began working with the RTI, complete documentation on the correct use of all the RTI services and calls was not available. JADS was surprised to learn post-test that the reliable distributor servicing the federates located in Albuquerque was incorrectly implemented. The following is a detailed discussion of the reliable distributor and how JADS implemented it for the federates in Albuquerque. Normally, every federate includes a reliable distributor (RELDISTR) based on the Internet TCP, since the RTI best effort communications mechanism provides neither guaranteed delivery to all message recipients nor in-order message delivery. The RELDISTR is used to send reliable data, i.e., guaranteed, in-order delivery from one federate to one or more other federates. During the analysis of Phase 2 data loss and data delay events, there were many instances of differential latencies for reliable messages sent from a federate on one test node to two or more federates on the other nodes. For example, a latency-sensitive jammer technique command message sent by the DSM federate at ACETEF might arrive with a normal latency at AFEWES and two of the JADS federates but be delayed to the other two JADS federates by hundreds of milliseconds or even seconds. When DMSO technical support was queried about such anomalies, they advised JADS that Phase 2 actually had three RELDISTR running on the radio frequency environment (RFENV) host at the JADS node in addition to single RELDISTR in the federates at the AFEWES and ACETEF nodes. In an effort to minimize the amount of traffic on the WAN, the DMSO liaison for JADS recommended that a single reliable distributor for the federates in the TCAC be used during Phase 3. This also was desirable to eliminate some types of differential latency problems. The RFENV federate was chosen to host the reliable distributor for the TCAC. The RFENV federate had to be started first, since all other federates would attempt to connect to its RELDISTR. Because of the two redundant RELDISTR in the runtime infrastructure executive (RTIEXEC) and federation executive (FEDEX) on the same SGI O2 host, redundant TCP connections were apparently created (based on post-test network packet sniffer evidence) between the RELDISTR on RFENV and

those at AFEWES and ACETEF. The extra RELDISTR and the redundant network pathways probably were the cause of some differential latency events during Phase 2. The RTIEXEC had its own RELDISTR, so for Phase 3 all federates in the TCAC were configured to use the RTIEXEC RELDISTR. However, because of a problem with RTI Version 1.3 Release 5, this required that the RTIEXEC be started with one version of the RTI.rid file, which then had to be replaced by a second version before the FEDEX and the RFENV federate were started. This minor inconvenience was handled by means of a UNIX shell script. There are two primary implications to ADS-based tests. First, federations with multiple federates on a local area network (LAN) should consider using a single RELDISTR per LAN. Second, RTI developers need to clearly document how to correctly implement nondefault configurations so that federations can take full advantage of the RTI features. Further implications are discussed below. Designers, instrumenters, and executors of real-time, performance federations with latency-sensitive messages sent via the RTI reliable communications protocol to two or more federates on other distributed test nodes need to carefully consider the potential consequences of differential latencies. That is because differential latencies can cause the federates to have different perceptions of if, and when, critical events happened. The original RTI developer's decision to use TCP for reliable traffic may have unavoidable, long-term, negative consequences that may cause trouble for some real-time, performance-oriented HLA-based simulations. For example, during RTI performance testing leading up to Phase 2, JADS learned that TCP implementations differ significantly, not only among those of different vendors, but also among different operating system version releases from the same vendor. A significant example of this is in the availability of the so-called TCP_NODELAY option that would allow the RELDISTR's TCP to acknowledge incoming TCP segments without delay. This option was not available in SGI's IRIX 6.3 operating system but was available in IRIX 6.5 Sun Solaris and some other operating systems. Use of this option within the RTI and by the federate developers for non-HLA federate components (e.g., the DSM PC software) probably would have reduced the latencies of reliable messages. Also, it is not at all clear that RTI developers using TCP for reliable distributor implementations have any means to guarantee that the TCP underlying a transmitting RELDISTR sends all copies of a reliable message intended for two or more recipients with minimal delay between outbound copy over a separate TCP connection. That is because the TCP protocol was never developed with this type of performance requirement in mind. It is also unclear as to whether intermediate RELDISTRs might introduce additional differential latencies because of a lack of control over the details of TCP actions on two or more independent TCP connections (a TCP connection consists of two pair of IP addresses and port numbers, one for the source and one for the destination).

- High performance federations can't treat the RTI as a black box. Just because federation designers are careful about which federates subscribe to data (in an effort to reduce WAN traffic) doesn't mean that the data aren't being sent to the federate anyway. Federation designers need to think carefully about the instrumentation for monitoring their federations, and that instrumentation should be in place well before the start of formal integration testing. Phase 2 showed that RTI loggers, DIS-style passive loggers, Internet ping probing, and network error printouts provide, at best, only circumstantial and limited evidence to diagnose the root causes of most data latency and data loss problems for HLA-based distributed simulations. RTI developers need to document how the RTI establishes multicast groups so that federation designers can take full advantage of what the RTI has to offer. Details on

how the RTI handles its communications are deliberately withheld from the user. This is done to encourage users to treat the RTI as a black box and adhere to the interface specification. This works for most users; however, T&E users have a need to know how communications are handled. JADS was surprised to learn post-test how the RTI really created multicast groups. Instead of separate multicast groups being established according to actual publish/subscribe topology, JADS best effort data were sent in a single multicast group to which all federates were connected. Each local instance of the RTI had to deal with all messages even if its federate did not subscribe to all messages. This should have been known in early design so that different implementations could have been tested. The following is a detailed discussion on how this worked within RTI 1.3 release 4 and 5. Also, there is a discussion of the data losses that were apparent and how the multicast implementation may have contributed. When the RTIEXEC starts execution, it transmits Internet Group Management Protocol (IGMP) "report" messages to join several IP multicast groups which, for the JADS federation, had Class D Internet addresses of the form 224.253.xxx.yyy. The FEDEX does the same when it begins, and so does each federate as it joins the federation. These IP multicast groups provide, via the UDP, the RTI's one-to-one and one-to-many best effort communications infrastructure. The RTI within each federate uses the stream map in the RID file (i.e., the file RTI.rid) to determine to which multicast group a particular type of best effort message should be sent to reach a specific federate or group of federates. The specific multicast group joined by a federate depends on when it joins versus the other federates. Also, as new federates join (or joined federates resign), the RTI dynamically redirects best effort traffic within the established multicast groups. After Phase 2, JADS discovered this behavior by using network packet sniffers on the SGI O2 hosts and eventually learned from the RTI developer that the stream map in the RID file provided to JADS caused all federates joining after the third federate to stop joining new multicast groups in addition to those already created. Instead, they joined a broadcast multicast group (224.253.1.0), and federation traffic formerly sent to specific multicast groups was redirected to that group. The result was that all federates received, even if they did not subscribe, almost all best effort messages, and the local RTI component (LRC) within the federates had to process and discard those unwanted messages. Thus, for example, the LRC in the hand-off federate, which did not subscribe to threat performance, had to receive, process, and discard five 20-hertz message streams from the platform and AFEWES federates. During Phase 2, there were many instances of best effort data losses that were unusual in two ways: they were one-way losses, meaning that messages between two or more federates were lost in one direction but not in the opposite direction; and they were selective losses, e.g., the DSM federate did not receive link health, live entity state, and threat performance messages from the platform federate at JADS, but did receive link health messages from the other three JADS federates. These losses cannot be explained by network problems such as a short outage on one of the T-1 lines, loss of crypto synchronization, etc., since those problems would affect all best effort traffic in both directions between two test nodes. This suggested that these selective, one-way best effort data losses might have been due to some problem with the RTI's use of IP multicast groups. Or, they might have been caused by "pruning" of some IP multicast addresses by the protocol independent multicast-dense mode (PIM-DM) routing protocol that the JADS routers used. Because of lack of adequate documentation for the RTI RID file, JADS unknowingly used a RID file with a stream map that was probably not appropriate for a federation with six or seven federates.

As a result, almost all our best effort data were sent to all federates unnecessarily loading some of them. Perhaps because of IP multicast-related bugs in RTI Version 1.3 Release 4, and/or router protocol pruning of RTI IP multicast addresses, JADS experienced many unusual, selective, one-way best effort data loss events. For runs 36 and 107, these events had consequences that caused unacceptable response times for some DSM jammer technique commands. The RTI.rid file could be modified with a new stream map to provide more multicast groups to the federation. The RTI developer's suggestion of using data distribution management could have been accepted but was rejected for Phase 3 for the same reason that it was not used for Phase 2; namely, there appeared to be a significant risk of adding unacceptable latencies to the real-time, performance-oriented federation. Regarding the second problem, PC-based network packet sniffers on the LANs leading to the routers were added at all three nodes to improve the instrumentation.

- Federations should experiment with different transport modes to determine the optimum mix of transport modes. RTI developers should have tools or performance measurements to guide federation developers as they design and integrate their architectures. TSPI data losses among platform federate, the DSM, AFEWES, and TCF occurred frequently during federation integration. JADS and DMSO investigated this problem. A work-around solution was found. This solution was a fixed join process for federates prior to each test run. After the solution was implemented, data losses among the DSM, AFEWES, and the platform federate were still observed. These losses manifested themselves in the apparent hovering aircraft observed in the FIT. It was not clear what caused the data loss, but dead reckoning aircraft position provided an acceptable solution. This data loss coupled with the dead reckoning implementation at AFEWES was the suspected cause of an extremely large miss distance value on one missile shot. RTI bundling of federate data for transmission made troubleshooting data flow and transmission problems more difficult. Our tools assessed hardware performance only. Instrumentation for federation performance evaluation used in Phase 2 was inadequate. It lacked the ability to examine data passed between RTI instances. Best effort data could be dropped by the network without notification or without any faults reported by the hardware. Phase 3 network instrumentation must be expanded to include network sniffers to monitor network traffic between the sites. Federation performance varied as the mix of reliable and best effort data changed. Through trial and error fewer problems with latency and data loss were noted if less reliable traffic was published within the federation. However, this was subjective because no tools were available to test the performance envelope of the architecture. Federation performance was poor when integration testing started. The link health messages were required to be published as best effort messages to correct this problem. This change was made late in the integration effort to further tune the architecture with the real federates. To correct for these problems LHC messages were published best effort during both ADS testing phases.

3.2 Programmatic

3.2.1 Procedures

- The number and types of procedural lessons learned JADS identified clearly substantiate a necessity to develop standards for the use of ADS.
- Network management and troubleshooting must be disciplined and organized with a thorough understanding and strong configuration control of the distributed testing network. This approach enabled the ETE Test Phase 2 team to quickly recover from initial pretest network difficulties and to go on and achieve five days of successful execution and data collection.
- Flexibility is also needed. When one of the ETE Test network's T-1 lines was disconnected, JADS personnel were able to quickly develop and implement a contingency plan. Upon restoration of the T-1 line, the network was soon returned to its original configuration and the test continued.
- Quantitative validation has limitations. JADS intent was to quantitatively verify missile simulation performance against live fire data. However, as only one live fly event was available to support the process, a modified approach including both quantitative and qualitative methods was used and successfully identified invalid results.
- The requirements for a distributed test must be clearly defined early in the planning phase. This includes user requirements, support agency's stated actions, and operations security requirements. Planning and coordination details will be much more involved than in a traditional, nondistributed test.
- Existing range procedures had to be modified for ADS. The existing test procedures were only written for individual facilities, so a new combined checklist was created for distributed testing applications.
- Get SUT experts involved from the beginning.
- Additional time is needed before the beginning and after the end of each testing period. One hour is recommended for setup, and two hours at the end for data logging, data archiving, data transfer, and laboratory reclassification.
- Briefings are needed before and after each mission.
- Configuration control is essential. This one obvious area was one of great challenge considering the many sites involved and the multiple uses of each site.
- The requirements for a distributed test must be clearly defined early in the planning phase. Detailed planning and coordination are required to ensure a common understanding of all requirements, procedures, and test objectives since individual facilities are generally unfamiliar with conducting coordinated, distributed T&E tests.
- Flexibility in planning is essential. When doing something that has never been done before, preconceived notions of how the test should be executed will have to change as more is learned. Be open to new ideas, as some of the old ideas from the early stages of a distributed test program may become very expensive to bring to fruition. The ETE Test Phase 2 was originally slated to have nine scenarios. As the requirements for each scenario increased, their development costs also grew. These added costs eventually led to the deletion of the last four scenarios.

- Plan for the unexpected. Halfway through the ETE Test Phase 2 one of the key T-1 lines was inadvertently disconnected. This delayed the test by two days during the most critical portion of the test while technicians restored the lines. Travel plans had to be changed and budgets were strained. If possible, plan for extra days on the end of a test period that can be eliminated if all goes well. It is much easier to return early than to stay longer.
- Minimize the impact of hardware problems. When using a complicated distributed testing network with a vast array of equipment, hardware problems will occur. Plan in such a way that unexpected hardware problems do not completely disrupt the test. During the ETE Test Phase 2, steps were taken to ensure that hardware problems did not disrupt the test for long periods. For example, data saves were accomplished frequently. In addition, the network was constantly monitored to ensure that hardware problems were fixed as soon as possible.
- Use a stepping stone approach to testing where each successive distributed test builds on the success of earlier tests. This "test, analyze, fix, test" approach, in concert with structured, independent testing of the network, will greatly improve the chances for successful distributed testing.
- Risk reduction testing prior to actual test execution will help test team personnel identify and resolve potential distributed testing system problems.
- Understand communication requirements. Because of some changes in the test, voice communication requirements between the Fort Hood node and the White Sands node were dramatically increased. The only way for those nodes to communicate was through the direct line to the TCAC. This tied up the direct line for extended periods. For the next test, another connection was added for direct communications between Fort Hood and White Sands.
- Briefings are needed before and after each distributed test. These briefings should include such information as the test objectives, telephone numbers to use for test control, the test configuration of each facility, instrumentation and data collection requirements, go/no go criteria, contingency and backup plans, and test conduct. A briefing checklist should be developed and used.
- Test control procedures should be well rehearsed. When many people are communicating on one phone line, a response order should be established and strictly followed to save valuable test time.
- Take advantage of the opportunities provided by distributed testing technology. At the beginning of Phase 2, the ETE Test team intended to log all operator actions in the LGSM. As the test progressed, the JADS analysts realized obtaining data from the LGSM operators would hamper their activities. Making use of the increased test time provided by the distributed testing environment, the JADS analysts were able to automate most of their LGSM data collection activities and reduce the impact on the LGSM operators.
- Effective data management is needed. Linked facilities can generate a large volume of data at distributed locations. Without careful planning, key data may not be collected and/or transmitted to the analysis center, and data collected at the network nodes may not be in a useful form for centralized analysis. Before distributed testing, a comprehensive data management plan must clearly identify the data to be collected at each network node, on-site processing of the data, and the data to be transmitted to the analysis center.
- Pretest rehearsals are also useful for improving evaluation procedures. The ETE Test team improved its data collection and analysis processes as a result of experiences from the functionality and integration and risk reduction tests.

- Have a centralized test control center. The JADS TCAC was configured to allow for convenient, instant communications with all the nodes. It acted as the central point of contact between the nodes and for all problems. The test controller kept track of test progress and documented any problems that occurred.
- Establish control over resources. Linking various facilities using distributed testing can require significant development of facility interface hardware and software. A well-organized approach by experienced personnel enabled the ETE Test team to surmount problems encountered at Fort Hood, the most complicated node in terms of getting all necessary hardware established and connected before Phase 2.
- Time sources must be synchronized using a "master clock" and then validated at each network node.
- Changes and upgrades to aircraft instrumentation delayed development. Specially instrumented aircraft were required to support the LFP flights. Because of the small number of such aircraft, the LFP schedule was very sensitive to periodic aircraft phase inspections, software upgrades, and higher priority missions.
- Laboratory replays served as an excellent method of test rehearsal.
- ADS test requirements must be clearly defined early in the test planning phase, since individual facilities are generally unfamiliar with conducting coordinated, distributed tests.
- Detailed planning for run management is necessary before testing commences. During daily testing, a run matrix was used to determine which runs were executed; what procedures were used to start the federates, models and simulators; and to initiate the run, stop the run and shut down of the federates. The work done during preliminary testing (e.g., FAT, FIT) provided a repeatable methodology for orderly federation operation that was used for the formal test. Nonetheless, problems were frequently encountered, errors were made, and unanticipated issues arose.
- JADS was highly dependent upon time synchronization of all federate computers and software. Any requirement for synchronization requires the ability to verify that the requirement is being met. For example, if one millisecond synchronization accuracy is required, then a capability to measure time between two computers at one millisecond precision is necessary. However, software tools were not available to measure accuracy at that level. In fact, testing time synchronization across the federation was more art than science. Even with time synchronization and the time cards implemented in all computers, instances were noted where time synchronization "slipped" affecting latency measurements. A few occurrences of time synchronization problems across the federation were observed requiring JADS to research particular runs after daily testing. JADS consistently followed documented time synchronization procedures and hardware settings. Site support personnel were relied upon to implement procedures and verify settings daily.
- Configuration changes on tools (analysis federate, ADRS display, DSM joining process, AFEWES dead reckoning algorithms) could have severe impacts. Configuration changes, even seemingly trivial ones, must be coordinated at all levels. JADS stressed configuration management procedures for Phase 3 and enforced their use.
- Operator boredom with the repetitiveness of test runs at AFEWES may have contributed to afternoon run differences. JADS attempted to minimize turn-around time between runs. The time between runs from start time to start time was usually between 6 and 8 minutes.
- Frequently, the government only knows in general terms what is needed to execute tests in a geographically distributed environment. Test design must mature to identify the specific

capabilities that each facility will provide before specifications are created. This generally precludes creating good performance specifications prior to contract award. Sufficient tasking must be included in the SOW to ensure that government interests are covered and the lead from the contractor has a leverage tool to ensure the work is executed on time with good quality. Sequential contract awards may be used to mitigate risks associated with loose SOWs. For JADS EW abbreviated SOWs and reduced deliverables resulted in differences in expectations between contractors and the government. The loosely defined SOW allowed the analysis team to continue to refine software requirements for a critical piece of software necessary for the test execution well beyond the date it should have been finalized. Several MOPs were modified from the non-traditional calculation to help measure ADS effects. This proved more difficult than expected. Since delivery schedules were not clearly defined, the contractor permitted these discussions to go on well beyond the time needed to code and test the software to meet the government's expected delivery date. All parties were trying to get the best insight into ADS effects on the EW Test measures while balancing impacts to the software. The problem was resolved when the government program manager froze software requirements and provided the contractor a specific delivery date. A second impact was related to the level of on-site test support. The loosely defined SOW allowed the contractor to reallocate on-site resources earlier in the test design to support other test activities. The reallocation was discussed with the government; however, the impact to on-site support during Phase 2 was not explicitly negotiated. As a result, the government received less support than expected. Once the software requirements were frozen, the updated software was delivered in time for test execution.

- Schedule may be the hardest factor in ADS testing to control because it is influenced by both internal factors (e.g., the ability of the different facilities to work together to identify and solve problems quickly) as well as external factors (e.g., other tests the facility must support and how much influence those tests have). Aggressive management of all development efforts and deliverables, effective risk management, and starting the effort with enough cost, schedule, and performance trade space are all essential ingredients to successful test execution. EW tests require several critical assets to execute successfully. Delays in one of these critical assets impact the overall test schedule. This is a larger problem with ADS since delays require rescheduling multiple facilities, each with unique time and asset constraints. The EW Phase 2 test schedule slipped because of delays in obtaining data from the EW Test Phase 1. The DSM required response time data from the system integration laboratory (SIL) test for calibration. The first two attempts to collect these data at the OAR and HITL tests failed causing the need to perform the SIL test. Because of these previous failures, the response time data were collected much later than required to prepare for Phase 2 test execution. As a result, this test phase was delayed to properly calibrate the DSM prior to test execution. JADS became more aggressive in managing the schedule and working with the supporting organizations to ensure that resources were ready and in place to support the test as scheduled. JADS also stated the test was not executable if it slipped again. No organization wanted to be responsible for canceling the test event, so extra efforts were made by everyone to ensure the test executed successfully.
- Perhaps the most important lesson learned from Phase 2 and the preparations for it was the critical importance of careful planning and preparations at the earliest stages of the program. It is better to avoid problems, since there may not be enough time and/or money to find and fix them later. This seems especially true for ADS programs. The nature of ADS brings

multiple facilities together, each having their own development style and practices and each bringing a potentially different understanding of the problem. This is very similar to having multiple facilities working together to develop a single software package. Any actions that reduce ambiguity in the interface design will reduce the risk of the program. This is very important for ADS-based tests since it may be difficult to slip test schedules when multiple facilities are involved. Hence, the importance of a good ICD and enforcing the same methods of compliance from the start of software development. An ICD was developed for the JADS federation to guide software developers. Two problems were identified relating to this ICD: (1) nonconformance to the ICD and (2) differences in interpretation of complex concepts. Prior to the test, the description of the coordinate transformation was agreed to be acceptable by all participants; however, facilities developed different implementations of the software when coding was finished. The problem was finally resolved when JADS provided sample transformation pairs for testing each facility's algorithm. These sample data points should have been included in the JADS ICD to avoid confusion. In some instances software was developed that did not conform to the ICD. Because of the lack of detailed acceptance testing these nonconformance problems were not found until very late in the integration process. As a result, decisions had to be made either to bring the software into conformance or to change the ICD in order to maintain test schedule. For example, problems with the federate message sequence numbers illustrate both the test and post-test impacts. For each instance of a simulation object, the federates should have used sequence numbers in outgoing messages starting from 1 and incremented by 1 for each successive message. However, because of a combination of ambiguous ICD wording and lack of early ICD compliance testing and enforcement, the TTH and AFEWES federates transmitted message sequences that did not conform to the same sequence numbering scheme. During Phase 2 test execution this became a problem with the DSM PC's real-time error checking for incoming SMC messages. The sequence number was used by the DSM to detect missing and out-of-order messages. Since the sequence numbers were not set correctly, the error reports were misleading and ineffective. During the post-test analysis, improper message sequence numbers for several message types made it more difficult to detect and analyze runs with data loss and latency problems for the ADS analysis process. In particular, it greatly complicated the calculation of overall latencies for the critical combination of outgoing SMC messages and the corresponding jammer technique command messages generated by the DSM. To correct for these problems message sequence counters were corrected for both the TTH and AFEWES threat federates for Phase 3. Wording in the ICD was changed to be less ambiguous.

- For future tests, the non-ADS effects should be understood well before test execution in order to assess each component. Modifications should be made to rules of engagement, MOP definitions, or the engagement scenario to better control the non-ADS effects or to at least be more able to separate the effects of the different sources of variance. Without the separation and control of the ADS and non-ADS effects, correlation between data sets may still prove to be an impossible task. Based on the analysis performed on the test data, it was discovered that non-ADS effects caused the largest amount of variance in most of the MOPs. Operator variance was the largest source of variance by far. Because the operator's choices on when to switch modes, how well to track, when to fire missiles, etc., affected the test data, constraining this was a very difficult problem. Even among the expert operators, variance from the operator was still larger than any variance caused by ADS effects such as data

latency, data loss, data corruption, etc. Furthermore, threat and SUT differences among the different test phases also contributed to the variance in the data sets. Without constraining the non-ADS effects on the MOPs collected, it was quite difficult to determine the ADS effects on the MOP data. Since the primary objective of the EW Test was to assess the ADS impacts to EW testing, the success at this project were mostly qualitative results based on the understanding of the MOP definitions and the qualitative results seen through the various test phases.

3.2.2 Costs

- The increased complexity of a distributed test can result in a small to medium increase in cost. However, actual costs will be application specific. Cost drivers include SE complexity, fidelity requirements, the requirement for experienced personnel, configuration management, network interfaces. Development of a new or modified simulation to support a distributed test will increase costs. The MITRE Corporation developed a distributed testing work breakdown structure (WBS) in support of JADS. The top-level WBS is presented in Table 24 below. The ADS cost impact column is an assessment of costs relative to a conventional test. Because actual costs will be program specific, it is difficult to quantify actual ADS cost impacts. In order to provide test planners with some insight into the impact ADS may have on a conventional test, JADS subjectively determined the degree of impact a particular ADS cost driver might have as small, medium or high. The increased complexity of an ADS test results in a small to medium increase in the cost of most categories. The cost drivers under the design and development category are simulations and interfaces. If a new or modified simulation must be developed, the cost can be medium to high. For example, a significant cost to the JADS ETE Test was the development of a high-fidelity representation of the Joint STARS radar system (ETE Test Phase 1). The cost to develop this simulation alone was \$4.2 million, which represents 53 percent of the entire ETE test program's cost.

Table 24. ADS Cost Impacts

WBS Element	ADS Cost Impact
Planning	Low increase
Concept Development	Low – medium increase
Design and Development	Medium increase
Installation, Integration and Test	Medium increase
Text Execution and Analysis	Large decrease – low increase

For a complete discussion of the MITRE WBS see *JADS Special Report on the Costs and Benefits of Distributed Testing* which can be found at www.jads.abq.com.⁸

⁸ After 1 March 2001 refer requests to the Joint Program Office Technical Library, 2001 North Beauregard St., Suite 800, Alexandria, Virginia 22311.

SBA advocates that the system developer deliver system representations and distributed product descriptions early in the acquisition process and maintain and update these representations throughout the system life cycle. STEP guidelines refer to a "maturing suite of models". These approaches should reduce the initial cost of the SUT simulation to the government and greatly reduce or eliminate the cost of this simulation to testers. The cost impact of a new or modified interface based on the JADS experience is judged to be medium to medium-high. JADS determined that communications links were not significant cost drivers, and that these costs are expected to decrease in the future. The cost impact on test execution and analysis runs the gamut from medium increases to large cost savings. The cost of test assets is directly related to the fidelity of the asset representation. In most cases a live asset costs the most, a virtual asset less, and a constructive asset the least. Distributed testing allows the tester to obtain the required fidelity at minimum cost. A related issue that can result in cost savings is test asset availability. In this case, live test assets are generally the least readily available, virtual more, and constructive the most available. Availability of test assets drives the test schedule especially when modifications and retesting are required. JADS identified several cost drivers during the execution of the three JADS tests. These cost drivers are listed to emphasize their importance in the planning and execution of a distributed test.

- SE complexity, as defined by the number and types of nodes, interfaces, and bandwidth requirements, will increase costs and risks to all phases of the distributed portion of the test program. Since a major virtue of distributed testing is to support the construction of complex test environments, the test planner must balance the need for complexity against the expense and fragility of the test architecture.
- Fidelity requirements for models can range from simple, script-driven models to high-fidelity, man-in-the-loop simulators. Fidelity and costs are directly proportional.
- It was the experience of JADS that test ranges and labs underestimated costs 10 to 15 percent. It is recommended that agreements with these organizations be formalized in a statement of capabilities, and that they be required to provide detailed cost estimates. The program test's priority number should be provided to the program management office's (PMO) T&E representative. Additionally, any provisions for schedule delay penalties should be agreed to. (These penalties are one of the costs of poor scheduling.)
- Test ranges, labs, and other federates should have experienced staff trained in distributed testing and HLA applications. If they do not have this capability, costs for elements associated with their support will be higher.
- JADS found that configuration management of hardware (HW), software (SW), NIUs, and models was more important to distributed testing than to traditional testing. A detailed configuration management plan and implementation process should minimize this risk.
- The cost of implementing distributed testing can be significantly reduced if it is planned for within the larger test program, i.e., while traditional testing approaches are being developed.

- Architecture integration should be fully understood to properly estimate it at the outset of the program. JADS found this activity to be consistently underestimated.
- Legacy test ranges with out-of-date equipment caused significant problems for the JADS tests. This could be clarified through a formal document from the test range.

Table 25 reports the actual costs to execute the three JADS tests.

Table 25. JADS Costs

JADS Costs	
SIT	
LSP	\$ 900,000
LFP	\$1,400,000
ETE Test	
Phase 1	\$4,700,000
Phase 2	\$2,200,000
Phase 3	\$ 700,000
Phase 4	\$ 300,000
EW Test	
OAR Phase	\$2,120,000
DSM Phase	\$2,700,000
ISTF Phase	\$1,700,000

- Distributed testing supports or enhances cost avoidance in several ways. Cost avoidance can be thought of as unplanned for cost savings. By identifying SUT problems earlier, you can not only avoid the expense associated with fixing the problems later, but you also avoid the expense of failing a more expensive test later. Similarly, the ability to identify tactics, techniques and procedures (TTP), training, data processing, and analysis problems earlier can all avoid the cost of expensive OAR test failures later. The LFP of the SIT provided a good example of cost avoidance that could be attributed to distributed testing. The AMRAAM initial operational test and evaluation failed a simultaneous, multiple-shot test event. The cause was an interoperability problem concerning the rear data link information going from the launch aircraft fire control radar to the AMRAAM. This interoperability problem would have been found in a LFP ADS test. The costs that would have been avoided include numerous tests and missiles to demonstrate that the fix worked; the dollars associated with the program delay; and the additional gray hairs for the program manager and test manager. Costs savings will be very program specific and closely related to the complexity of the test environment (potential for increased savings) and the number of new simulations and interfaces that need to be developed instead of being reused. The potential for cost avoidance can be judged to be high, but the ability to predict the amount for any given program is very low.

3.2.3 Personnel

- An experienced program manager or system integrator is needed to oversee facility development, because of the difficulty in coordinating several diverse facilities to successfully integrate an ADS-linked configuration. ADS requires strong systems integration and systems engineering expertise. This responsibility is difficult to manage by participants supplying items to be integrated. If the sponsor is unable to provide the expertise of a systems engineer and integrator, an independent source should be used. Subject matter experience and knowledge of computers and communications technology are essential for the systems integrator. Simulations, when used in distributed testing, should be carefully planned and developed. The distributed test controller must also be in close communication with each organization modifying simulations crucial to the test. The ETE Test Phase 2 succeeded because of the relatively high degree of reliability of the simulations used in the test. If simulation execution problems had occurred, the ETE Test team had arranged for a quick response by the personnel needed to fix those difficulties.
- Have a centralized test control center with test controllers who are extremely familiar with the test and network configuration.
- Personnel involved in a distributed test should understand the "big picture." When people are geographically separated, it becomes easy for them to focus on their own individual portion of the test. When problems arise, personnel who understand the entire test and the overall network will find solutions much faster.
- Distributed tests require personnel distribution. When many distributed nodes are required for the successful completion of a test, personnel will need to be located at these nodes. The complexity and input an individual node contributes should guide the assignment of personnel. The ETE Test Phase 2 required several people at the Fort Hood, Northrop

Grumman and TCAC nodes; only one person was needed at the White Sands node. The Fort Sill node used only resident personnel.

- Test controllers need to be extremely familiar with the test and network configuration. THE EW Phase 2 Test succeeded partly because it had an experienced test controller with the necessary tools to evaluate problems and the authority to make meaningful decisions regarding test problems.
- The number of computers, intricate execution procedures, and high number of test events performed sequentially created a very workload intensive environment at the TCAC and other locations during testing periods. Manning requirements at the TCAC, AFEWES, and ACETEF involved 14 dedicated JADS personnel during the two-week test period. Site manning (three persons) at AFEWES was insufficient. It was determined that one additional person would be required for rotation among JETS, Tactical Air Mission Simulator (TAMS) and the simulator stations. JADS reviewed and updated the site manning matrix for Phase 3.

4.0 Summary

4.1 Program Issue Accomplishment

The JADS charter focused on three issues: What is the present utility of ADS, including DIS, for T&E; what are the critical constraints, concerns, and methodologies when using ADS for T&E; and what are the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future. As cited in paragraph 3.0 in the "Lessons Learned" section of this report, distributed architectures can be powerful tools capable of generating real data on the performance of a SUT. It's important to remember that the term "distributed testing" can appropriately be substituted for "advanced distributed simulation" in some cases.

4.1.1 Utility

Roles for ADS can be identified for both DT&E (in which the general objective is to determine the SUT's ability to meet specifications using preproduction subsystems) and OT&E (in which the general objective is to determine the SUT's ability to meet user's operational effectiveness and suitability requirements using production-level systems in realistic combat scenarios). The underlying ADS technology can support DT&E and OT&E equally well.

JADS concluded the technology, when properly applied, produces valid test data over a broad range of systems and types of tests. JADS identified three broad areas of benefits to using ADS:

- The ability to overcome current test limitations
- The ability to identify failure modes earlier
- The ability to conduct end-to-end testing

Associated with these benefits to distributed testing is the ability to impact program cost through either cost savings or cost avoidance. JADS identified potential for saving costs in two studies where distributed testing would allow for a reduction in live testing while providing a more complete test environment. JADS demonstrated cost avoidance by using distributed testing to identify failure modes earlier and by using distributed testing to rehearse live missions, thus identifying potential live test failures.

4.1.2 Concerns

JADS determined the primary concerns for implementing ADS are programmatic rather than technical. Distributed testing is not a "plug and play" technology. Developing a distributed test environment requires a strong engineering methodology and attention to detail. Additionally, scheduling multiple facilities to support both the integration and execution of a test is often very challenging. Costs remain a concern. Most existing facilities were not designed to be linked and require some modification, along with appropriate interfaces, before linking is possible. This cost can be significant but can be amortized over all phases of the acquisition process.

4.1.3 Constraints and Limitations

JADS identified four areas where the application of this technology is constrained.

- The lower limit of latency is fixed by the speed of light, and there are a small percentage of test programs that involve very tightly coupled interactions between the SUT and other players in which latency will be a constraint.
- Another technical constraint is the ability to present representations of synthetic targets to live players. This is especially true for presenting synthetic targets to human operators in a live vehicle such as an aircraft or a tank. Its also a problem for radio frequency and infrared sensors on many live vehicles.
- There is a limited ability to represent dynamic environmental effects among live and virtual players. Currently there are no means to capture weather effects or man-made effects such as smoke and weather in real time from a live range and synchronize them with similar effects in a virtual or constructive simulation.
- The most prevalent distributed testing constraint is the availability and capability of current simulations. Distributed testing must rely on the use of simulations that were not necessarily designed to work together. In most cases it is more cost effective to develop interface units than it is to modify existing simulations.

4.1.4 Requirements

JADS identified several requirements that, if delivered, will improve the capability to implement this technology in test and evaluation.

- Open systems standards for technical interoperability between live, virtual, and constructive simulations
- Multilevel security capabilities
- Distributed test control standards
- On-call networking capability providing low latency, deterministic performance
- Distributed testing expertise at test ranges and facilities
- Support from DoD test and evaluation and acquisition leadership

4.2 General Accomplishments

The JADS JTF developed four distributed test environments connecting distributed test facilities, live air and ground nodes, laboratories, and simulation facilities. These environments were used to conduct three successful multiphase distributed tests across three domains of systems: precision guided munitions, C4ISR, and electronic warfare. Testing was conducted using the environments for approximately 215 hours and an additional 200 hours of integration, risk reduction, and test rehearsals.

JADS was responsible for the production of two important products. The first was a DIS-compliant version of the Army's interactive simulation called Janus. JADS provided funding to the TRAC-WSMR to make the required improvements to Janus. The improved version of Janus

has been used in support of multiple tests and exercises in addition to providing the battlefield environment for the JADS End-to-End Test.

Another product developed as a direct result of a JADS test was the VSTARS. It is an emulation of all the radar functionality from the E-8C portion of the Joint STARS system. VSTARS continues to be used to support the Joint STARS T&E evaluation program and is planned to become an integral part of the Joint STARS Mission Crew Training System. VSTARS has been used to provide virtual Joint STARS radar for multiple exercises. The internal synthetic aperture radar (SAR) simulation, Advanced Radar Imaging Emulation System (ARIES) is being ported to provide an internal SAR training capability for the Army's common ground station (CGS).

JADS also developed products in-house with the help of Science Applications International Corporation contractors. The first product was the Analysis Toolbox. It is a set of C++ routines integrated into a single user interface that allows users to perform near real-time and post-test analysis by graphically plotting test data consisting of PDUs. This product provided dynamic capabilities that did not exist before JADS. The second product was an RTI logger for HLA simulations that resides between the federate software and the application program interface (API). This product also filled an analysis void and has been widely distributed by JADS for use by other organizations.

4.3 Program Impact

The potential of distributed testing as a feasible test tool, one with the ability to overcome many traditional shortcomings in present day T&E methodologies, is exciting. JADS investigated this potential and developed a legacy program to ensure the vital information gets to the proper organizations in a format they can understand and use.

The legacy of JADS was much more than a voluminous, unread report. The legacy of the JADS JT&E covered a broad range of issues for the T&E community. JADS has defined its legacy program as "all actions JADS takes to ensure that its products are fully incorporated into the user community." There were three aspects to this effort.

1. Educate the user community and instill distributed testing into its thought processes. JADS developed a training course that was offered at JADS and off site upon request. The course covered ADS concepts; the potential benefits of using ADS; an overview of the JADS test events; lessons learned from completed tests; and methodologies for assessing and using ADS. The course described ADS, encouraged thinking and planning processes that include ADS, and included recommendations on how and when it might be used. More than 1500 T&E professionals from DoD, industry, and international organizations have attended these courses. In addition, JADS used a variety of media and forums to spread the word to the test and evaluation community. This activity included thirty seven test or special reports, a quarterly newsletter, a World Wide Web site, a variety of brochures, information booths at T&E conferences and symposia, technical papers, videos, and interactive multimedia compact disks.

2. Equip the user community with the proper distributed testing knowledge, procedures, and tools. JADS developed reports, training modules, roadmaps, checklists, etc., so that testers can

assess whether distributed testing is right for them in a particular application. JADS also produced products so that, having made the determination that distributed testing is worthwhile in their situation, testers can develop plans to develop a distributed test environment and conduct a distributed test. Procedures were developed for communication, network design, installation and checkout; verification, validation and accreditation (VV&A); test control and analysis; and security. Specialized software tools were developed for network monitoring, data collection, and real-time data analysis. Products developed span the entire spectrum of distributed testing from evaluation to planning to execution and analysis. JADS included information in a variety of media about the prudent uses of distributed testing, technical knowledge, VV&A strategies, pitfalls, lessons learned, and a final interpretation of results.

3. Institutionalize the products of the JADS JT&E for lasting value. JADS worked with a variety of agencies and repositories to arrange for the long-term availability of JADS reports and products. After 1 March 2001 refer requests for information to Headquarters Air Force Operational Test and Evaluation Center History Office (HQ AFOTEC/HO), 8500 Gibson Blvd. SE, Kirtland Air Force Base, New Mexico 87117-5558, or SAIC Technical Library, 2001 North Beauregard St., Suite 800, Alexandria, Virginia 22311. In this way, future T&E professionals can access what was learned and reap the benefits long after JADS has ceased to exist. Additionally, as experience in the use of distributed testing as a testing tool proliferates, future efforts may delve further into this new technology. The groundbreaking work of JADS will then be available as a starting point for further study.

Perhaps more importantly, JADS has a variety of intangible products. Some of these products include knowledge and experience gained by T&E facility personnel as a result of the tests; infrastructure and computing power paid for by JADS but distributed to the appropriate facilities upon completion of tests; increased willingness of testing professionals to consider distributed testing as a possible solution to their testing challenges; and the tools to evaluate distributed testing for how it may fit a particular application.

The impact of JADS will be real change, where warranted, and the knowledge and tools needed to implement those changes for better T&E in the future. Better T&E can mean T&E at lower cost; more complete T&E at the same cost; higher cost but greatly enhanced fidelity; or in some cases, the only way to test because of safety and/or environmental constraints. Better T&E through the intelligent use of distributed testing is all of these and more. Giving our warfighters the best we can possibly give them is our ultimate goal. The proper use of distributed testing will help create weapon systems with lower overall life-cycle costs that come from better design, testing, and evaluation before being put into the hands of our warfighters. This is the true legacy of the JADS JT&E.

5.0 Definitions

A

Accreditation. See: distributed simulation accreditation, model/simulation accreditation.

Accuracy. The degree of exactness of a model or simulation relative to an established standard with high accuracy implying low error. [DIS]

Activity. An event that consumes time and resources and whose performance is necessary for a system to move from one event to the next. [DIS]

Advanced Distributed Simulation (ADS). A set of disparate models or simulations operating in a common synthetic environment. The ADS may be composed of three modes of simulation: live, virtual and constructive, where the latter can be seamlessly integrated within a single exercise. See also: live simulation; virtual simulation; constructive simulation. [DIS]

Aggregate. An activity that combines individual entities into a singular entity. Contrast with: disaggregate. [DIS]

B

Battlespace. The three-dimensional battlefield. [DIS]

Benchmark. (v) The activity of comparing the results of a model or simulation with an accepted representation of the process being modeled. (n) The accepted representation of the modeled process. [DIS]

Bit. The smallest unit of information in the binary system of notation. [IEEE 1278.1]

Broadcast. A transmission mode in which a single message is sent to all network destinations, i.e., one-to-all. Broadcast is a special case of multicast. Contrast with: multicast; unicast. [IEEE 1278.2]

C

Compatible. Two or more simulations are DIS compatible if (1) they are DIS compliant, and (2) their models and data that send and interpret PDUs support the realization of a common operational environment among the systems (coherent in time and space). Contrast with: compliant, interoperable. [DIS]

Compliant. A simulation is DIS compliant if it can send or receive PDUs in accordance with IEEE Standard 1278 and 1278 (working drafts). A specific statement must be made regarding the qualifications of each PDU. Contrast with: compatible, interoperable. [DIS]

Conceptual Model. A description of the content and internal representations which are the user's and developer's combined concepts of the exercise. It includes logic and algorithms and explicitly recognizes assumptions and limitations. [DIS]

Constructive Simulation. Models and simulations that involve simulated people operating simulated systems. See Also: war games; higher order model (HOM). [DIS]

Continuous Model. (1) A mathematical or computational model whose output variables change in a continuous manner; that is, in changing from one value to another, a variable can take on all intermediate values. For example, a model depicting the rate of air flow over an airplane wing. Syn: continuous-variable model. (2) A model of a system that behaves in a continuous manner. Contrast with: discrete model. [DIS]

Continuous Simulation. A simulation that uses a continuous model. [DIS]

Continuous-Variable Model. See: continuous model. [DIS]

Control Station. (1) A facility which provides the individual responsible for controlling the simulation and the capability to implement simulation control as protocol data units (PDUs) on the distributed interactive simulation (DIS) network.

Syn: simulation - management station. [DIS]

D

Data. Representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation or processing by humans or automatic means. [DIS]

Database. A collection of data organized according to a schema to serve one or more applications. [DIS]

Data Certification. The determination that data have been verified and validated. (1) Data producer certification is the determination by the data producer that data have been verified and validated against documented standards of criteria. (2) Data user certification is the determination by the application sponsor or designated agent that data have been verified and validated as appropriate for the specific M&S usage. [DIS]

Data Logger. A device that accepts protocol data units (PDUs) from the network and stores them for later replay in the same time sequence as the PDUs were originally received. See also: protocol data unit (PDU). [IEEE 1278.3]

Data Validation. The documented assessment of data by subject area experts and comparison to known or best-estimate values. (1) Data producer validation is that documented assessment within stated criteria and assumptions. (2) Data user validation is that documented assessment of data as appropriate for use in an intended M&S. [DIS]

Data Verification. The use of techniques and procedures to ensure that data meet specified constraints defined by data standards and business rules. (1) Data producer verification is the use of techniques and procedures to ensure that data meet constraints defined by data standards and business rules derived from process and data modeling. (2) Data user verification is the use of techniques and procedures to ensure that data meet user specified constraints defined by data standards and business rules derived from process and data modeling and that data are transformed and formatted properly. [DIS]

Data Verification, Validation, and Certification. The process of verifying the internal consistency and correctness of data, validating that they represent real world entities appropriate for their intended purpose or an expected range of purposes, and certifying them as having a specified level of quality or as being appropriate for a specified use, type of use, or range of uses. The process has two perspectives: producer and user process. See: data validation, data verification, and data certification. [DIS]

Dead Reckoning. See: remote entity approximation.

Deaggregate. See: disaggregate. [DIS]

Distributed Interactive Simulation (DIS). A synthetic environment within which humans may interact through simulation(s) at multiple sites networked using compliant architecture, protocols, standards, and databases (DoDD 5000.59P)

Digital System Model (DSM). A digital representation of an actual or conceptual system that involves mathematics, logical expressions, or computer simulations that can be used to predict how the system might perform or survive under various conditions or in a range of hostile environments.

E

Electronic Battlefield. See: synthetic environment. [DIS]

Entity. Any component in a system that requires explicit representation in a model. Entities possess attributes denoting specific properties. See: simulation entity. [DIS]

Environment. (1) The texture or detail of the domain, such as cities, farmland, sea states, etc. (2) The external objects, conditions, and processes that influence the behavior of a system (such as terrain relief, weather, day, night, terrain cultural features, etc.) [DIS]

Event. (1) An occurrence that causes a change of state in a simulation. See also: conditional event; time-dependent event. (2) The instant in time at which a change in some variable occurs. [DIS]

Event-Driven Simulation. See: event-oriented simulation. [DIS]

Event-Oriented Simulation. A simulation in which attention is focused on the occurrence of events and the times at which those events occur; for example, a simulation of a digital circuit that focuses on the time of state transition. Syn: event-driven simulation; event-sequenced simulation. [DIS]

Event-Sequenced Simulation. See: event-oriented simulation. [DIS]

Exercise. (1) One or more sessions with a common objective and accreditation. (2) The total process of designing, assembling, testing, conducting, evaluating, and reporting on an activity. See: simulation exercise. Syn: experiment, demonstration. [DIS, IEEE 1278.3]

F

Fidelity. (1) The similarity, both physical and functional, between the simulation and that which it simulates. (2) A measure of the realism of a simulation. (3) The degree to which the representation within a simulation is similar to a real-world object, feature, or condition in a measurable or perceivable manner. See also: model/simulation validation. [DIS, IEEE 1278.1]

Field. (1) A series of contiguous bits, treated as an instance of a particular data type, that may be part of a higher level data structure. (2) An external operating area for actual vehicles or live entities. See: field instrumentation. [DIS, IEEE 1278.1]

G

Graphical Model. A symbolic model whose properties are expressed in diagrams. For example, a decision tree used to express a complex procedure. Contrast with: mathematical model; narrative model; software model; tabular model. [DIS]

Ground Truth. The actual facts of a situation without errors introduced by sensors or human perception and judgment. [DIS]

H

Human-in-the-Loop Model. See: interactive model.

Human-Machine Simulation. A simulation carried out by both human participants and computers, typically with the human participants asked to make decisions and a computer performing processing based on those decisions. [DIS]

I

Interactive Model. A model that requires human participation. Syn: human-in-the-loop model. [DIS]

Interoperable. Two or more simulations are DIS interoperable for a given exercise if they are DIS compliant, DIS compatible, and their performance characteristics support a fair fight to the fidelity required for the exercise. Contrast with: compatible, compliant. [DIS]

Interoperability. (1) The ability of a set of simulation entities to interact with an acceptable degree of fidelity. The acceptability of a model is determined by the user for the specific

purpose of the exercise, test, or analysis. (2) The ability of a set of distributed interactive simulation applications to interact through the exchange of protocol data units. [DIS]

L

Live Entity. A perceptible object that can appear in the virtual battlespace but is unaware and non-responsive (either by intent, lack of capability or circumstance) to the actions of virtual entities. See also: field instrumentation. Contrast with: live instrumented entity. [DIS]

Live Instrumented Entity. A physical entity that is in the real world and can be represented in the distributed interactive simulation (DIS) virtual battlespace which can be manned or unmanned. The live instrumented entity has internal and/or external field instrumentation (FI) devices/systems to record and relay the entity's surroundings, behavior, and/or reaction to events. If the FI provides a two-way link, the events that affect the live instrumented entity can be occurring in the virtual battlespace as well as the real world. See also: field instrumentation, live entity. [DIS]

Local Area Network (LAN). A class of data network which provides high data rate interconnection between network nodes in close physical proximity. [IEEE 1278.3]

M

Measure of Performance (MOP). Measure of how the system/individual performs its functions in a given environment (e.g., number of targets detected, reaction time, number of targets nominated, susceptibility of deception, task completion time). It is closely related to inherent parameters (physical and structural) but measures attributes of system behavior. See also: measures of effectiveness (MOE). [IEEE 1278.3]

Model. (1) An approximation, representation, or idealization of selected aspects of the structure, behavior, operation, or other characteristics of a real-world process, concept, or system. Note: Models may have other models as components. (2) To serve as a model as in (1). (3) To develop or use a model as in (1). (4) A mathematical or otherwise logical representation of a system or a system's behavior over time. [DIS]

Model/Simulation Accreditation. The official certification that a model or simulation is acceptable for use for a specific purpose. See also: distributed simulation accreditation. Contrast with: model/simulation validation, model/simulation verification. [DoDD 5000.59]

Model/Simulation Validation. The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended use(s) of the model. See also: distributed simulation validation, fidelity. Contrast with: model simulation accreditation, model simulation verification. [DoDD 5000.59]

Model/Simulation Verification. The process of determining that a model implementation accurately represents the developer's conceptual description and specifications. See also: distributed simulation verification. Contrast with: model simulation accreditation, model simulation validation. [DoDD 5000.59]

N

Network Filter. A system to selectively accept or reject data received from the network. [DIS]

Network Node. A specific network address. See: node. Contrast with: processing node. [DIS]

Node. A general term denoting either a switching element in a network or a host computer attached to a network. See: processing node; network node. [IEEE 1278.1, IEEE 1278.2]

O

Operational Environment. A composite of the conditions, circumstances, and influences which affect the employment of military (or other) forces and the decisions of the unit commander or person in charge. [DIS]

P

Platform. A generic term used to describe a level of representation equating to vehicles, aircraft, missiles, ships, fixed sites, etc., in the hierarchy of representation possibilities. Other representation levels include units (made up of platforms) and components or modules (which make up platforms.) [DIS]

Protocol Data Unit (PDU). A DIS data message that is passed on a network between simulation applications according to a defined protocol. [IEEE 1278.1]

R

Real Time. In modeling and simulation, simulated time advances at the same rate as actual time; for example, running the simulation for one second results in the model advancing time by one second. Contrast with: fast time, slow time. [DIS]

Resolution. (1) The degree to which near equal results values can be discriminated. (2) The measure of the ability to delineate picture detail. [DIS]

S

Scenario. (1) Description of an exercise (initial conditions). It is part of the session database which configures the units and platforms and places them in specific locations with specific missions. (2) An initial set of conditions and time line of significant events imposed on trainees or systems to achieve exercise objectives. See: field exercise. [DIS, IEEE 1278.3]

SIMNET (Simulator Networking). The prototype distributed simulation upon which DIS was based. [DIS]

Simulate. To represent a system by a model that behaves or operates like the system. See also: emulate. [DIS]

Simulated Time. Time as represented within a simulation. Syn: virtual time. See also: fast time; real time; slow time. [DIS]

Simulation. (1) A model that behaves or operates like a given system when provided a set of controlled inputs. Syn: simulation model. See also: emulation. (2) The process of developing or using a model as in (1). (3) An implementation of a special kind of model that represents at least some key internal elements of a system and describes how those elements interact over time. [DIS]

Simulation Environment. (1) Consists of the natural physical environment surrounding the simulation entities including land, oceans, atmosphere, near-space, and cultural information. (2) All the conditions, circumstances, and influences surrounding and affecting simulation entities including those stated in (1). [DIS]

Simulation Exercise. An exercise that consists of one or more interacting simulation applications. Simulations participating in the same simulation exercise share a common identifying number called the exercise identifier. These simulations also utilize correlated representations of the synthetic environment in which they operate. See: live simulation. [IEEE 1278.1, IEEE 1278.2]

Simulation Fidelity. Refers to the degree of similarity between the simulated situation and the operational situation. [IEEE 1278.3]

Simulation Time. (1) A simulation's internal representation of time. Simulation time may accumulate faster, slower, or at the same pace as real time. (2) The reference time (e.g., universal coordinated time) within a simulation exercise. This time is established ahead of time by the simulation management function and is common to all participants in a particular exercise. [DIS, IEEE 1278.1]

Simulator. (1) A device, computer program, or system that performs simulation. (2) For training, a device which duplicates the essential features of a task situation and provides for direct practice. (3) For distributed interactive simulation (DIS), a physical model or simulation of a weapons system, set of weapon systems, or piece of equipment which represents some major aspects of the equipment's operation. [DIS]

Site. (1) An actual physical location at a specific geographic area, e.g., the Fort Knox Close Combat Test Bed (CCTB). (2) A node on the network used for distributed simulation such as the Defense Simulation Internet (DSI) long haul network. (3) A level of configuration authority within a DIS exercise. [DIS]

V

Validation. See: data validation, distributed simulation validation, face validation, model/simulation validation. [DIS]

Verification. See: data verification, distributed simulation verification, model/simulation verification

Verification and Validation (V&V) Proponent. The agency responsible for ensuring V&V is performed on a specific model or simulation. [DIS]

Vignette. A self-contained portion of a scenario. [DIS]

Virtual Battlespace. The illusion resulting from simulating the actual battlespace. [DIS]

W

War Game. A simulation game in which participants seek to achieve a specified military objective given pre-established resources and constraints; for example, a simulation in which participants make battlefield decisions and a computer determines the results of those decisions. See also: management game. Syn: constructive simulation; higher order model (HOM). [DIS]

Wide Area Network (WAN). A communications network of devices which are separated by substantial geographical distance. Syn: long haul network. [IEEE 1278.3]

6.0 Acronyms

A/C	aircraft
A ² ATD	Anti-Armor Advanced Technology Demonstration
AASI	Advanced Aircraft Simulation Interface
ACE	analysis and control element
ACETEF	Air Combat Environment Test and Evaluation Facility, Patuxent River, Maryland; Navy facility
ADEWS	Advanced Distributed Electronic Warfare System; Army sponsored
ADRS	Automated Data Reduction Software
ADS	advanced distributed simulation
ADT	air data terminal
AFATDS	Advanced Field Artillery Tactical Data System
AFB	Air Force Base
AFEWES	Air Force Electronic Warfare Evaluation Simulator, Fort Worth, Texas; Air Force managed with Lockheed Martin Corporation
AFOTEC	Air Force Operational Test and Evaluation Center, Kirtland Air Force Base, New Mexico
AIM	air intercept missile
ALQ-131	a mature self-protection jammer system; an electronic countermeasures system with reprogrammable processor developed by Georgia Tech Research Institute
AMRAAM	advanced medium range air-to-air missile
API	application program interface
ARIES	Advanced Radar Imaging Emulation System
ASAS	All Source Analysis System
ATACMS	Army Tactical Missile System
AVTB	Aviation Test Bed at Fort Rucker, Alabama
BMIC	Battle Management Interoperability Center at Naval Air Warfare Center, Point Mugu, California
C4I	command, control, communications, computers and intelligence
C4ISR	command, control, communications, computers, intelligence, surveillance and reconnaissance
CCF	Central Control Facility, Eglin Air Force Base, Florida
CGS	common ground station
CONOPS	concept of operations
CROSSBOW	Office of the Secretary of Defense committee under the Director, Operational Test and Evaluation
CSU	channel service unit
DIS	distributed interactive simulation
DMAP	data management and analysis plan
DMSO	Defense Modeling and Simulation Organization, Alexandria, Virginia
DoD	Department of Defense
DSI	Defense Simulation Network
DSM	digital system model

DSU	data service unit
DT&E	developmental test and evaluation
ECM	electronic countermeasures
EPF	engineering protofederation
ES	electronic support
ESPDU	entity state protocol data unit
ETE	JADS End-to-End Test
EW	electronic warfare; JADS Electronic Warfare Test
FAT	federate acceptance test
FBCB ²	Force XXI Battle Command, Brigade and Below
FED	federation
FEDEP	federation development and execution process
FEDEX	federation executive
FIT	federate integration test
FOM	federation object model
FOT&E	follow-on operational test and evaluation
FTP	file transfer protocol
FY	fiscal year
GB	gigabyte
GDT	ground data terminal
GPS	global positioning system
HITL	hardware-in-the-loop (electronic warfare references)
HLA	high level architecture
HW	hardware
HWIL	hardware-in-the-loop (system integration references)
IADS	Integrated Air Defense System
ICD	interface control document
ID	infantry division; identification
IDNX TM	Integrated Digital Network Exchange
IEEE	Institute of Electrical and Electronics Engineers
IGMP	Internet Group Management Protocol
INS	inertial navigation system
IP	Internet protocol
IPPD	integrated product and process development
IPT	integrated product team
IR	infrared
IRIG	Inter-Range Instrumentation Group
IRIX	operating system for the Silicon Graphics, Inc.
ISTF	installed systems test facility
J/S	jamming-to-signal ratio
JADS	Joint Advanced Distributed Simulation, Albuquerque, New Mexico
Janus	interactive, computer-based simulation of combat operations
JCSAR	Joint Combat Search and Rescue
JECSIM	Joint Electronic Combat Testing Using Digital Simulations
JETS	JammEr Techniques Simulator
Joint STARS	Joint Surveillance Target Attack Radar System

JSF	Joint Strike Fighter
JT&E	joint test and evaluation
JTF	joint test force
JTMD	Joint Theater Missile Defense
LAN	local area network
LFP	Live Fly Phase
LGSM	light ground station module
LHC	link health check
LRC	local runtime infrastructure component
LSP	Linked Simulators Phase
M&S	modeling and simulation
Mbps	megabits per second
MCTS	Mission Crew Training System
MISILAB	Missile Simulation Laboratory, Eglin Air Force Base, Florida
MITRE	company that provided engineering services
MOE	measure of effectiveness
MOP	measure of performance
MOT&E	multiservice operational test and evaluation
MSL	missile
NATO	North Atlantic Treaty Organization
NETVisualizer™	software that displays real-time bandwidth use in a rolling bar graph format for quick visual reference
NIU	network interface unit
NTP	network time protocol
OAR	open air range
OPTEMPO	operations tempo
OSD	Office of the Secretary of Defense
OT	operational test
OT&E	operational test and evaluation
OTA	operational test agency
PC	personal computer
PDU	protocol data unit
PGM	precision guided munitions
PIM-DM	protocol independent multicast-dense mode
PMO	program management office
P-value	probable value
RDAPAS	Radar Detection and Performance Analysis System
RDL	rear data link
RELDISTR	reliable distribution
RF	radio frequency
RFENV	radio frequency environment
RID	runtime infrastructure initialization data
RM&A	reliability, maintainability and availability
ROE	rule of engagement
RTI	runtime infrastructure
RTIEXEC	runtime infrastructure executive

SAIC	Science Applications International Corporation
SAR	synthetic aperture radar
SATCOM	satellite communications
SBA	Simulation Based Acquisition
SCDL	surveillance control data link
SE	synthetic environment
SEOT	synthetic environment operational test
SETI	Synthetic Environment Tactical Integration
SGI	Silicon Graphics, Inc.
SIL	system integration laboratory
SIM	simulation
SIMLAB	Simulation Laboratory, Naval Air Warfare Center, China Lake, California
SINGARS	Single-Channel Ground and Airborne Radio System
SIT	JADS System Integration Test
SMC	source mode change
SME	subject matter experts
SMS	stores management system
SOW	statement of work
SPECTRUM®	a network analysis package developed by Cabletron Systems
SPJ	self-protection jammer
SRS	software requirements specification
STEP	simulation, test and evaluation process
STORM	Simulation, Testing and Operations Rehearsal Model
STTAR	synthetic test and training architecture
SUT	system under test
SW	software
T&E	test and evaluation
T/E	tracking error
T-1	digital carrier used to transmit a formatted digital signal at 1.544 megabits per second
T-3	28 T-1 lines in one; the aggregate data rate is 44.746 megabits per second
TAC	target analysis cell
TACCSF	Theater Air Command and Control Simulation Facility
TAFSM	Tactical Army Fire Support Model
TAMS	Tactical Air Mission Simulator
TCAC	Test Control and Analysis Center, Albuquerque, New Mexico
TCF	test control federate
TCP	transmission control protocol
TDP	time-space-position information data optimizing processor
TEMP	test and evaluation master plan
TGT	target
TMD	Theater Missile Defense
TRAC	U.S. Army Training and Doctrine Command (TRADOC) Analysis Center
TSLA	Threat Simulator Linking Activity
TSPI	time-space-position information
TTH	terminal threat hand-off federate

TTP	tactics, techniques and procedures
UDP	user data protocol
UMB	umbilical
UNIX™	registered trademark of UNIX Systems Laboratories
V&V	verification and validation
VPG	virtual proving ground
VSTARS	Virtual Surveillance Target Attack Radar System
VTP	Virtual Torpedo Project
VV&A	verification, validation, and accreditation
WAN	wide area network
WBS	work breakdown structure
WSIC	Weapons System Integration Center, Naval Air Warfare Center, Point Mugu, California
WSMR	White Sands Missile Range, New Mexico
WSSF	Weapon System Support Facility, China Lake, California

7.0 References

7.1 Utility Reports

The Utility of Advanced Distributed Simulation for Precision Guided Munitions Testing, Major Steven J. Sturgeon, Dr. Leslie L. McKee and James Duffany, May 1998

The Utility of Advanced Distributed Simulation for Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance Testing, LTC Patrick M. Cannon, Maj Mark F. Scott and Dr. Leslie L. McKee, August 1999

The Utility of Advanced Distributed Simulation for Electronic Warfare Testing, Maj Darrell L. Wright, November 1999

JADS Executive Report on the Utility of Distributed Testing, Eric L. Keck, December 1999

The Utility of Distributed Testing (compact disk)

7.2 Special Reports

JADS Final Report, December 1999

JADS Final Video (video)

JADS Management Report, LTC Patrick Cannon and Maj Olivia Tapia, January 2000

JADS Special Report on the Costs and Benefits of Distributed Testing, MAJ Michael L. Roane and Norma Slatery, December 1999

A Test Planning Methodology-From Concept Development Through Test Execution, John Reeves and Dr. Larry McKee, November 1999

JADS Special Report on Distributed Test Control, Earl E. Barnes and Greg Grundhoffer, December 1999

JADS Special Report on High Level Architecture, Maj Darrell L. Wright and Jerry Black, January 2000

JADS Special Report on Networking and Engineering, MSgt Charles P. Ashton, August 1999

JADS Special Report on Programmatic Challenges to Distributed Testing, Lt Col James M. McCall, John Reeves and Dr. Larry McKee, November 1999

JADS Special Report on Verification, Validation and Accreditation of Distributed Tests, MAJ Michael Roane and Gary Marchand, October 1999

7.3 System Integration Test

System Integration Linked Simulators Phase Final Report, MAJ Steven J. Sturgeon and Dr. Leslie L. McKee, July 1997

System Integration Live Fly Phase Final Report, MAJ Steven J. Sturgeon and Dr. Leslie L. McKee, March 1998

System Integration Test (compact disk)

System Integration Test (video)

7.4 End-to-End Test

End-to-End Test Interim Report Phase 1, Lt Col James M. McCall and Gary Marchand, August 1998

End-to-End Test Interim Report Phase 2, MAJ Paul Hovey, February 1999

End-to-End Test Interim Report Phase 3, MAJ Paul Hovey and Gary Marchand, May 1999

End-to-End Test Interim Report Phase 4, MAJ Paul Hovey and Gary Marchand, August 1999

End-to-End Test (compact disk)

End-to-End Test (video)

7.5 Electronic Warfare Test

Electronic Warfare Test Interim Report Phase 1, Maj Darrell L. Wright and James Charlton, March 1999

Electronic Warfare Test Interim Report Phase 1, Data Analysis (SECRET), Maj Darrell L. Wright and James Charlton, October 1999

Electronic Warfare Test Interim Report Phase 2, Maj Darrell L. Wright, September 1999

Electronic Warfare Test Interim Report Phase 3, Maj Darrell L. Wright and Capt Roman M. J. Nation, November 1999

Electronic Warfare Test Classified Results Report (SECRET), Maj Darrell L. Wright and Capt Roman M. J. Nation, November 1999

Electronic Warfare Test (compact disk)

Electronic Warfare Test (video)

7.6 Verification, Validation and Accreditation

End-to-End Test Verification and Validation Plan, Gary Marchand, July 1997

Phase 1 Verification and Validation Report, Gary Marchand, August 1998

Phase 2 Verification and Validation Test Plan for the End-to-End Test, Gary Marchand, February 1998

Phase 2 Verification and Validation Report for the End-to-End Test, Gary Marchand, February 1999

Phase 3 Verification and Validation Test Plan for the End-to-End Test, Gary Marchand, September 1998

Phase 3 and Phase 4 Verification and Validation Report for the End-to-End Test, Gary Marchand, August 1999

7.7 Technical Papers

ADS Testing of C4ISR Systems, Gary Marchand, September 1999

An Advanced Distributed Simulation (ADS) Test Implementation Methodology, Dr. Larry McKee, September 1999

An Advanced Distributed Simulation Test Planning Methodology, John Reeves, December 1998

A Never Ending Story the Need for Verification and Validation Throughout the Life of a Test, Gary Marchand, September 1999

Application of the Analysis Federate in the Joint Advanced Distributed Simulation Joint Test Force Electronic Warfare Phase II Test, MAJ William S. Murphy Jr. and MAJ Michael L. Roane, December 1999

A VV&A Strategy for Advanced Distributed Simulation in Support of a Test, Gary Marchand, December 1996

Air-to-Air Missile T&E Using Live Aircraft Linked to a Missile HWIL Simulation, Dr Larry McKee, June 1998

Air-to-Air Missile Testing Using Advanced Distributed Simulation, Dr Larry McKee, July 1997

An Advanced Distributed Simulation Inclusive Test Planning Methodology, John Reeves, December 1998

Analysis Tools and Procedures for Distributed Networks, Captain Sandra Smith, December 1998

Collection and Analysis of Quality Data in a Distributed Simulation Test Environment, Dean G. Gonzalez and Jerry Black, December 1996

Compensating for Latency Variations in Air-to-Air Missile T&E Using Live Aircraft Linked to a Missile HWIL Simulation, Dr Larry McKee, March 1998

Data Collection in an HLA Federation, Jerry Black, December 1998

Determining and Expressing Runtime Infrastructure Requirements, Clyde Harris and Major Darrell Wright, March 1998

Distributed Simulation and Test and Evaluation: A Midterm Report on the Utility of Advanced Distributed Simulation to Test And Evaluation, Col Mark Smith, June 1998

Distributed Test and Evaluation of Aerospace Systems: The Joint Advanced Distributed Simulation Joint Test Force Experience, Col Mark E. Smith, February 2000

High Level Architecture Runtime Infrastructure Test Report, Maj Darrell Wright, Clyde Harris and Jerry Black, August 1998

JADS Electronic Warfare Baseline Testing, Maj Darrell Wright, June 1999

JADS End-to-End Test - Distributed Simulation Using Satellites, Gary Marchand, September 1999

JADS End-to-End Test—The Final Chapter, Gary Marchand, December 1999

Joint Test Environment for Electronic Warfare Testing, Maj Mark McCall, December 1997

Latency and its Effects on the Fidelity of Air-to-Air Missile T&E Using Advanced Distributed Simulations, Dr Larry McKee, September 1997

Modification of the Entity State PDU for Use in the End-to-End Test, MAJ Terry Schmidt and Gary Marchand, December 1996

Network Design and Performance of the System Integration Test, Linked Simulators Phase, Gregory Grundhoffer, David Brown, and TSgt Charles Ashton, December 1996

Statistical Techniques for Determining the Repeatability of Man-in-the-Loop System Performance Data, Capt Sandra Smith, Capt Roman Nation and Maj Darrell Wright, December 1999

Testing Advanced Distributed Simulation for Use in Electronic Warfare Test and Evaluation, Maj Darrell Wright and Clyde Harris, September 1997

Testing and Training in a Command, Communications, Control, and Intelligence (C3I) Framework, John Reeves, December 1997

The Applicability of ADS to Precision Guided Munitions Testing, Dr Larry McKee, September 1998

The Benefits of Using Advanced Distributed Simulation for Air-to-Air Missile Testing, Dr. Larry McKee, November 1998

The Development of a Real Time Stochastic Radar Simulation (VSTARS), Gary Marchand and MAJ Terry Schmidt, December 1996

The Future of Digital Terrain in Distributed Simulations, Capt Rodney Houser, December 1998

The JADS Analysis Toolbox (A Tool for Analysis of Distributed Simulations), Dean Gonzalez and Jerry Black, March 1999

The Utility of ADS for Precision Guided Munitions Testing, Dr. Larry McKee, September 1998

Tuning RTI Performance for an Electronic Warfare T&E Federation, Clyde Harris and Jerry Black, December 1998

Using High Level Architecture for Electronic Warfare Test and Evaluation, Clyde Harris, November 1998

Validation of Air-to-Air Missile Performance in Advanced Distributed Simulations, Dr Larry McKee, July 1997

Verification and Validation of Distributed Air-to-Air Missile Tests, Dr. Larry McKee, March 1999

Verification and Validation of the JADS End-to-End Test-The Final Chapter, Gary Marchand, December 1999

VSTARS--A STEP Success Story, Gary Marchand, December 1998

7.8 Tools

Distributed Testing - A Tool for the Tester's Toolbox (compact disk). This CD presents the JADS training course including sections on

- Why Distributed Testing
- Technology Concepts of Distributed Testing (DIS and HLA)
- Applications of Distributed Testing (PGM, C4ISR, and EW testing)
- Test Concept Development
- Distributed Test Planning and Execution
- Methodologies and Special Topics (V&V, cost analysis, test control, terrain/feature database, RTI performance testing, networking, programmatic challenges, time synchronization and security)

JADS Analysis Toolbox, Dean Gonzalez and Jerry Black.

The JADS Analysis Toolbox Users Manual, Dean Gonzalez and Jerry Black, June 1999

The toolbox comprises a set of C++ routines integrated into a single user interface. Users can view tabulations and plots of distributed interactive simulation protocol data units data in near real time, can replay or get selected data in a text-readable format from the JADS logfile(s) post test, and can obtain predefined plots and tabulations of PDU statistics for post-test analyses.

Runtime Infrastructure Logger. This is a set of tools that log messages to and from the RTI.

Web Site

<http://www.jads.abq.com>

After 1 March 2001, refer requests to Headquarters Air Force Operational Test and Evaluation Center History Office (HQ AFOTEC/HO), 8500 Gibson Boulevard SE, Kirtland Air Force Base, New Mexico 87117-5558 or Science Applications International Corporation (SAIC) Technical Library, 2001 North Beauregard Street, Suite 800, Alexandria, Virginia 22311.